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of the
American Association *of* Petroleum Geologists

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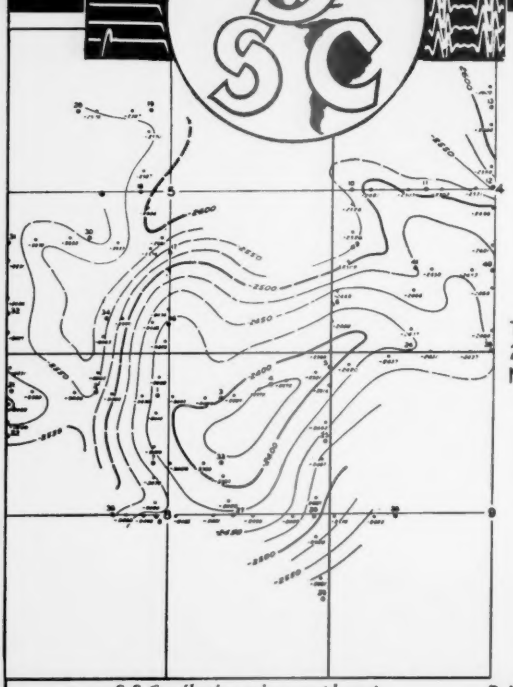

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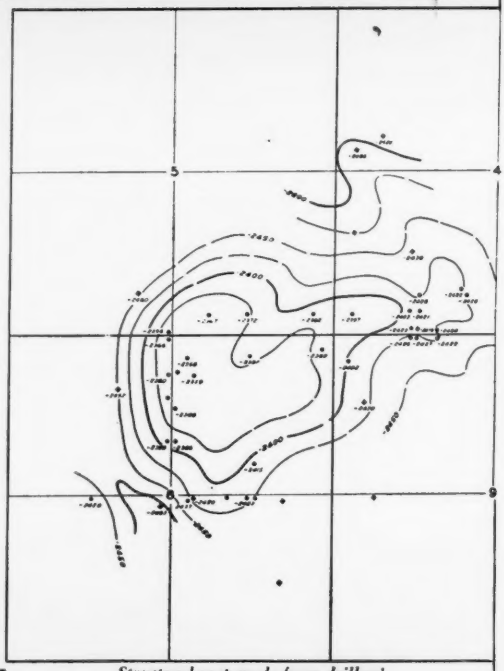

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EDITORIAL AND PUBLICATION OFFICE AND ASSOCIATION HEADQUARTERS, 708 Wright Building, 115 and 117 West Third Street, Tulsa, Oklahoma. Post Office, Box 979, Tulsa 1.

BRITISH AGENT: Thomas Murby & Co., 40 Museum Street, London, W. C. 1.

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Entered as second-class matter at the Post Office at Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

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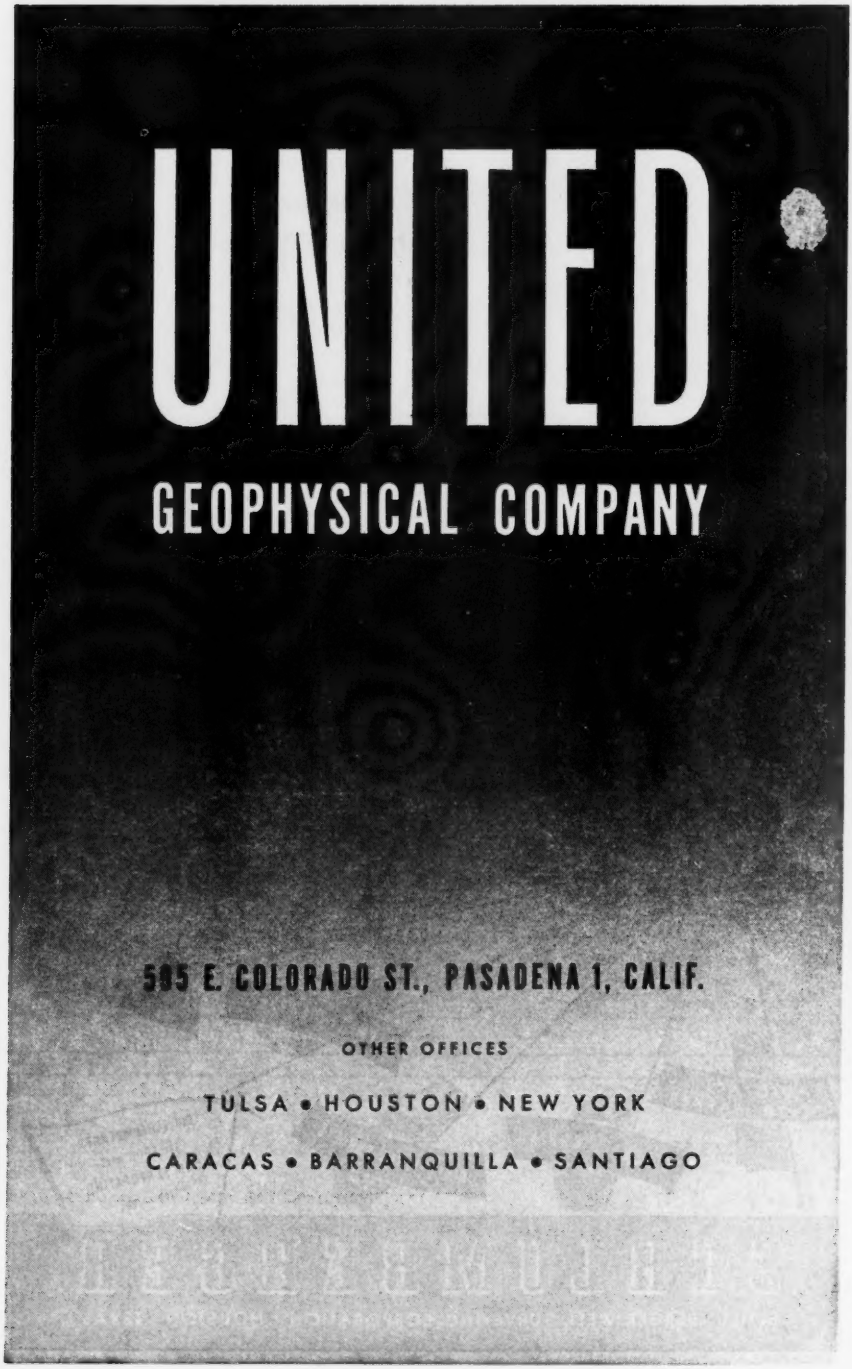
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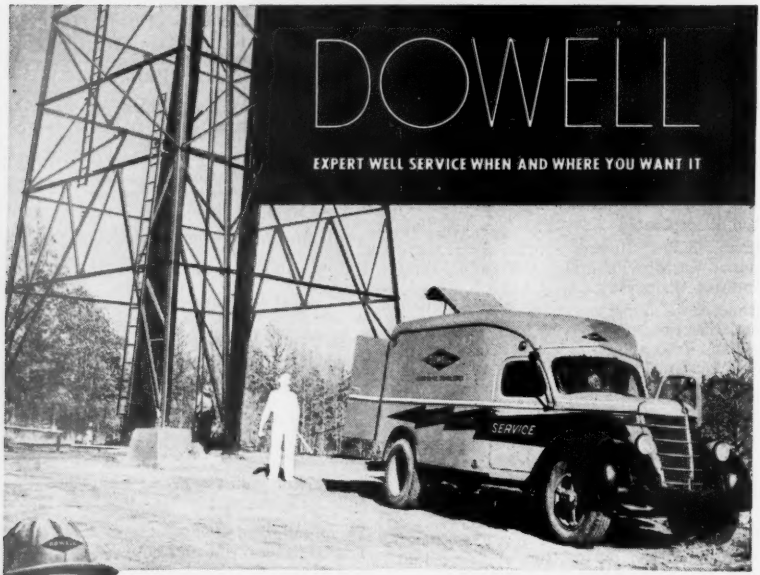

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NOVEMBER, 1946

WEST EDMOND OIL FIELD, CENTRAL OKLAHOMA[1]

D. A. McGEE[2] AND H. D. JENKINS[3]
Oklahoma City, Oklahoma

ABSTRACT

The West Edmond oil field of central Oklahoma, discovered April 5, 1943, had produced more than 32 million barrels of oil from 704 wells, through December 31, 1945. The field produced and ran 2,597,624 barrels of oil in November, 1945. Fifteen new wells were completed during the month of December. On January 1, 1946, there were thirty drilling wells in the field. Through December 31, 1945, an estimated 46,000,000 MCF of gas had also been produced. Seventeen of the 704 wells are producing oil from the "Bartlesville" sand of lower Pennsylvanian age; 687 wells are producing oil from the Hunton limestone of Siluro-Devonian age. The field embraces an area of 30,000 proved acres with 1,500 to 2,000 semi-proved acres.

The field is located on the northeastern rim of the Anadarko basin of western Oklahoma. The local structure is monoclinal, dipping west into the basin at approximately 125 feet to the mile. Oil production in the Hunton group is the result of a wedge-out of the upper or Bois d'Arc limestone member against the Nemaha ridge on the east and a regional wedge-out of the Hunton group on the north. Oil accumulation generally is in coarsely crystalline limestone. The Bois d'Arc limestone reaches a maximum known thickness of 140 feet on the west side of the field and wedges out completely at the east, thus delineating the eastern limits of production. There is some minor oil production in the field from the lower or Chimneyhill limestone member of the Hunton limestone where porosity is developed locally. In one small area in the northeastern part of the pool, oil is produced from the middle or Haragan-Henryhouse due to a local development of porosity.

INTRODUCTION

The West Edmond field, located in T. 12 N., R. 4 W., T. 13 N., R. 4 W., T. 14 N., R. 4 and 5 W., and T. 15 N., R. 4 and 5 W., Oklahoma, Canadian, Logan, and Kingfisher counties, Oklahoma, is in geographical extent and probable oil recovery the largest single oil field found in Oklahoma since the discovery of the Oklahoma City field in December, 1928. The discovery of the field without the help of geological, geophysical, or other recognized technical aids, the fact

[1] Read before the Association at Chicago, April 3, 1946, Manuscript received, July 13, 1946.

[2] Executive vice-president, Kerr-McGee Oil Industries, Inc.

[3] Chief geologist, Kerr-McGee Oil Industries, Inc. The writers wish to thank George Cobb, T. W. Wheeler, and Otis Danielson for valuable assistance in writing this paper, and A. J. Montgomery for much helpful criticism.

that the oil and gas accumulated in a stratigraphic or wedge-type limestone trap, and the rapid development of the productive area under war time conditions, are some of the interesting features of the field.

The purpose of this paper is to discuss the geological conditions in the area and their relationship to the accumulation of the oil in the West Edmond field and to give an account of drilling, production, and conservation practices and problems. The field has been developed along orderly lines, and good drilling, completion, and production records have been kept. Most of this information has been available for study.

HISTORY

As shown on Figure 1, the West Edmond field lies northwest of the Oklahoma City field.

FIG. 1.—Location map.

The field is in an area that has been considered, geologically, as on the west flank or basinward slope of the "Granite ridge" line of folding, on which a number of the most important oil fields of central Oklahoma are located. Over a period of years, especially following the discovery of a new oil pool along the "Granite ridge," such as Oklahoma City, Edmond, Britton, or Crescent, the general area of the West Edmond field has been explored intensively by geological and geophysical methods. This work led, at various times, to the drilling of a few dry "Wilcox" sand tests.

In 1942, Ace Gutowsky of Oklahoma City acquired a block of acreage in the southwest part of T. 14 N., R. 4 W., the southeast part of T. 14 N., R. 5 W., and the northwest part of T. 13 N., R. 4 W. For months he solicited the support of oil companies and individuals interested in the oil business, but, being unable to

supply geological or geophysical data that made the area appear attractive, he could not sell sufficient acreage on his prospect to finance the drilling of a well. He then enlisted the aid of B. D. Bourland of San Antonio, and together they interested the Fox brothers and Herbert Schmitz of Chicago in the venture. A contract was signed for the drilling of the well to 7,350 feet, at which depth Gutowsky expected to encounter the "Wilcox" sand. The location was made for the Wagner No. 1 in the NW. ¼, NW. ¼, SW. ¼ of Sec. 32, T. 14 N., R. 4 W., Oklahoma County, and actual drilling commenced on January 2, 1943. After the drilling was started, several oil companies purchased acreage from Gutowsky and Bourland, and the well was drilled deeper when the "Wilcox" sand was not found at 7,350 feet. The Wagner reached the total depth of 7,690 feet in the "Wilcox" sand on March 25, 1943. In the course of the drilling, a showing of oil had been found in the Hunton limestone. Seven-inch (outside-diameter) casing was set at 7,301 feet through the Hunton limestone, which was encountered at 6,866 feet. A cable-tool unit was moved onto the location on March 31, 1943; the well was bailed dry and was perforated on April 5, 1943. Eleven holes were shot in the casing from 6,951 feet to 6,956 feet, and the well started to head through the open casing. On April 28, after additional perforating and after 2½-inch tubing had been run, the well flowed 522 barrels of oil in 24 hours through a 9/32-inch choke. The oil was light and of 41° Bé. gravity, corrected to 60°F. The original bottom-hole pressure taken on May 3, 1943, showed a corrected value at minus 5,864 datum of 3,110 pounds per square inch. The State Conservation Department gave the well an allowable of 300 barrels per day plus a discovery allowable of 94 barrels per day for a period of one year.

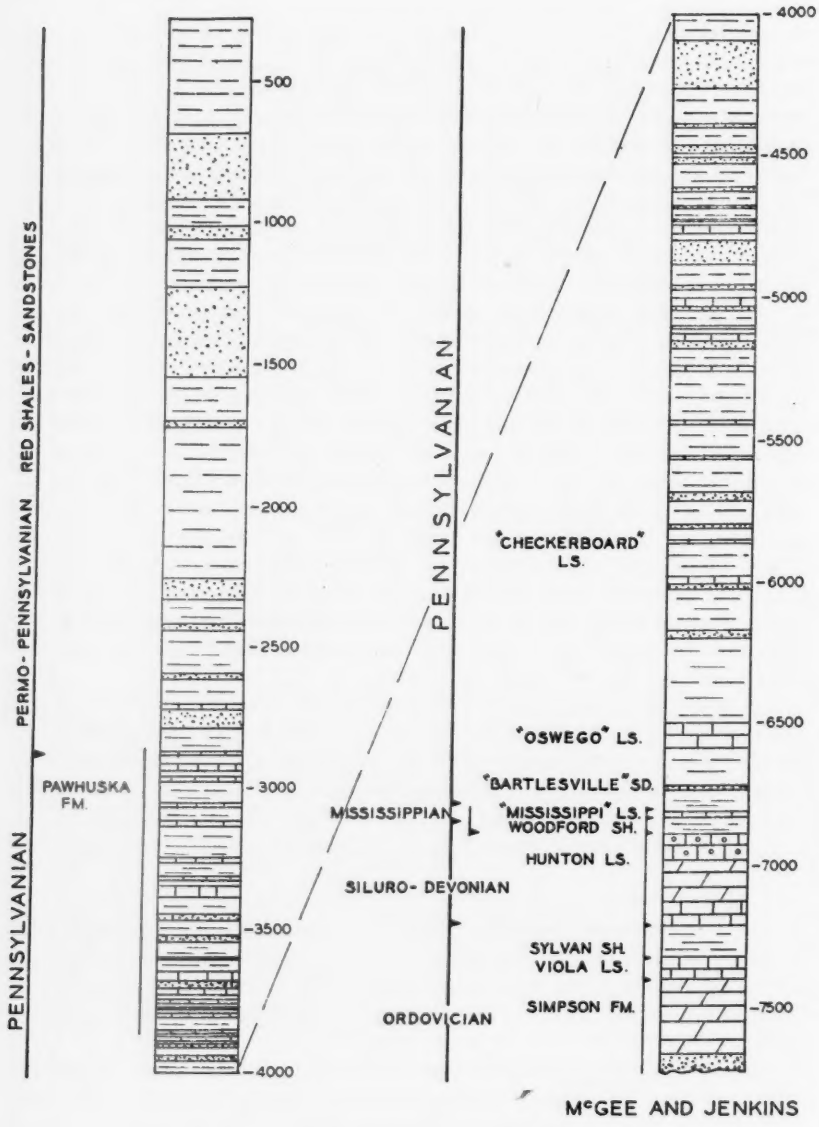
Gutowsky gives credit for the discovery of the West Edmond field to the "doodle-bug." During the long period of time when he was attempting to interest the oil business in Oklahoma in putting some money into the venture, he had a number of the oil country's best known "doodle-bugs" survey the location. It is rumored that some failed to find evidence of oil accumulation but that the majority agreed that large oil production would be found when the well was drilled.

STRATIGRAPHY

Surface formations.—The Hennessey shale of the Enid group of lower Permian age crops out in the entire area of the West Edmond field. With the exception of the valley of Deer Creek which runs from southwest to northeast across T. 14 N., R. 4 W., the Hennessey shale forms unwooded, flat to gently rolling pasture lands.

Subsurface formations.—The names used for identifying the subsurface formations in the West Edmond field are, for the most part, those which have come into common usage in the near-by Oklahoma City, Britton and Edmond fields. Figure 2 shows the geologic section, graphically, with a few of the more prominent beds identified.

The actual correlation with type localities in many cases has not been satis-



COLUMNAR SECTION

WEST EDMOND FIELD

FIG. 2.—Columnar section.

factorily made, and no attempt is made here to do other than to identify them by their commonly known field names. Wells in the West Edmond field penetrate on an average 6,900 feet of rocks above the Hunton limestone. Of this 6,900 feet of sediments approximately 6,600 feet are of Permo-Pennsylvanian age. The remaining 100 feet are of Mississippian age. The subsurface horizons are easily identified. There are a number of key beds, continuous throughout the area, that are regular in their occurrence. The stratigraphy of the field has been well known from the time of the discovery, since it is similar in all respects to the stratigraphy of near-by fields where the geological section has previously been described in complete detail. Samples of drill cuttings have been carefully saved, and with a few exceptions electrical logs have been run on all wells drilled in the field. Consequently, stratigraphy has not been a problem in the development of the West Edmond field.

PERMIAN

The Permian section consists of red shales and sands at the top and red and brown shales with streaks of sand in the middle part. These grade into gray shales with thin streaks of limestone in the basal part of the section.

PENNSYLVANIAN

The Pennsylvanian section consists largely of gray shales with a few persistent limestones and three or four thick sand bodies. The commonly identified marker beds are the "Pawhuska" limestone series at 3,300 feet to 3,800 feet, the "Tonkawa" limestone series at 4,800 feet, the "Avant-Dewey" limestone at 5,000 feet to 5,200 feet, the "Checkerboard" limestone at 5,850 feet, and the "Oswego" limestone at 6,500 feet, all approximate depths. The well developed sand bodies are at approximately 4,100 feet, 4,500 feet, and 4,800 feet. There is a long shale interval above the "Checkerboard" which contains only a few thin streaks of sand and limestone from approximately 5,300 feet to 5,800 feet, and another shorter shale interval from 6,100 feet to 6,500 feet. A shale section below the Oswego limestone has locally developed in it the "Bartlesville" sand, which ordinarily occurs about 225 feet below the top of the "Oswego" or about 80 feet above the base of the Pennsylvanian. This sand zone varies from a sandy shale to a fairly clean shaly sand, and ranges in thickness from zero to 30 feet. East of the field, higher on the "Granite ridge" line of folding, the "Bartlesville" sand is, in places, only 30 feet above the base of the Pennsylvanian.

PRE-PENNSYLVANIAN

Unlike the near-by Edmond, Britton, and Oklahoma City fields, post-Mississippian erosion and truncation did not remove entirely the Mississippian beds from the area of the West Edmond field. These beds thicken on the west edge and in the north part of the field. This thickening of the Mississippian beds largely occurs in the topmost member, the Mississippian limestone. A relatively thin section of Mississippian rocks is present in the discovery well.

MISSISSIPPIAN LIMESTONE

The Mississippian limestone is gray, granular to finely crystalline limestone. The thickest section drilled to date is 204 feet.

CHATTANOOGA SHALE

The Chattanooga shale under the Mississippian limestone is dark brown bituminous shale. It is approximately 60 feet in thickness.

HUNTON LIMESTONE

The Hunton limestone of Siluro-Devonian age, principal producing zone in the West Edmond field, is composed of three members: the Bois d'Arc limestone member at the top, the Haragan-Henryhouse in the middle, and the Chimneyhill member at the bottom. The total Hunton section varies in thickness in the field, due principally to a variation in thickness of the top or Bois d'Arc limestone member. In the discovery well the Hunton limestone was 330 feet thick, the Bois d'Arc limestone was 90 feet, the Haragan-Henryhouse 110 feet and the Chimneyhill 130 feet thick. At the south end of the field the Bois d'Arc limestone is thickest (130 feet); consequently, the whole Hunton section is thickest. In the middle part of the field the Bois d'Arc limestone thins to approximately 60 feet and at the present northern limits of production has a thickness of approximately 20 feet.

Early drilling in the field rather definitely indicated that the production in the Hunton limestone was largely limited to the Bois d'Arc limestone member. In the later development of the field, especially in Secs. 9, 10, 15, 16, T. 14 N., R. 4 W., substantial production has been found in the lower two members of the Hunton limestone so that it has become the practice in parts of the field to drill through the entire Hunton section before setting casing. Those wells that have been drilled through the Hunton section and outpost wells which had been drilled around the field prior to its discovery indicate a rather uniform thickness in the lower two members. The thinning in the Bois d'Arc limestone member at the top of the Hunton is due largely to pre-Mississippian erosion and truncation and not to deposition.

The Bois d'Arc limestone member, where it is present in maximum thickness, consists of approximately 60 feet to 65 feet of coarsely crystalline limestone at the top, 40 feet to 50 feet of finely crystalline dolomite, with streaks of limestone, in the middle part, and 20 feet to 30 feet of oölitic limestone, which is dolomitic at the base.

The Haragan-Henryhouse, the middle member of the Hunton limestone, is gray to tan finely crystalline dolomite.

The Chimneyhill member, the basal member of the Hunton, is medium to coarsely crystalline limestone with here and there a streak of dolomite.

SYLVAN SHALE

The Sylvan shale, Ordovician in age, which underlies the Hunton limestone, has a thickness of approximately 100 feet. It is a pale green to gray splintery shale.

VIOLA-SIMPSON SECTION (ORDOVICIAN AGE)

In the discovery well there is an interval of 335 feet from the top of the Viola limestone to the top of the "Second Wilcox" sand. Of this interval 75 feet are Viola limestone and the remainder Simpson dolomite with streaks of limestone, with the exception of a sandy 10-foot zone 225 feet below the top of the Viola limestone, which represents the "First Wilcox" sand zone.

The 75 feet of Viola limestone is divided into an upper 55 feet of coarsely crystalline gray to white limestone and a lower 20 feet of dense to lithographic limestone.

The Simpson dolomite section is composed largely of tan to gray finely crystalline dolomite. The "Second Wilcox" sand is composed of frosted, rounded, well assorted grains. This sand was penetrated 30 feet in the discovery well.

STRUCTURE

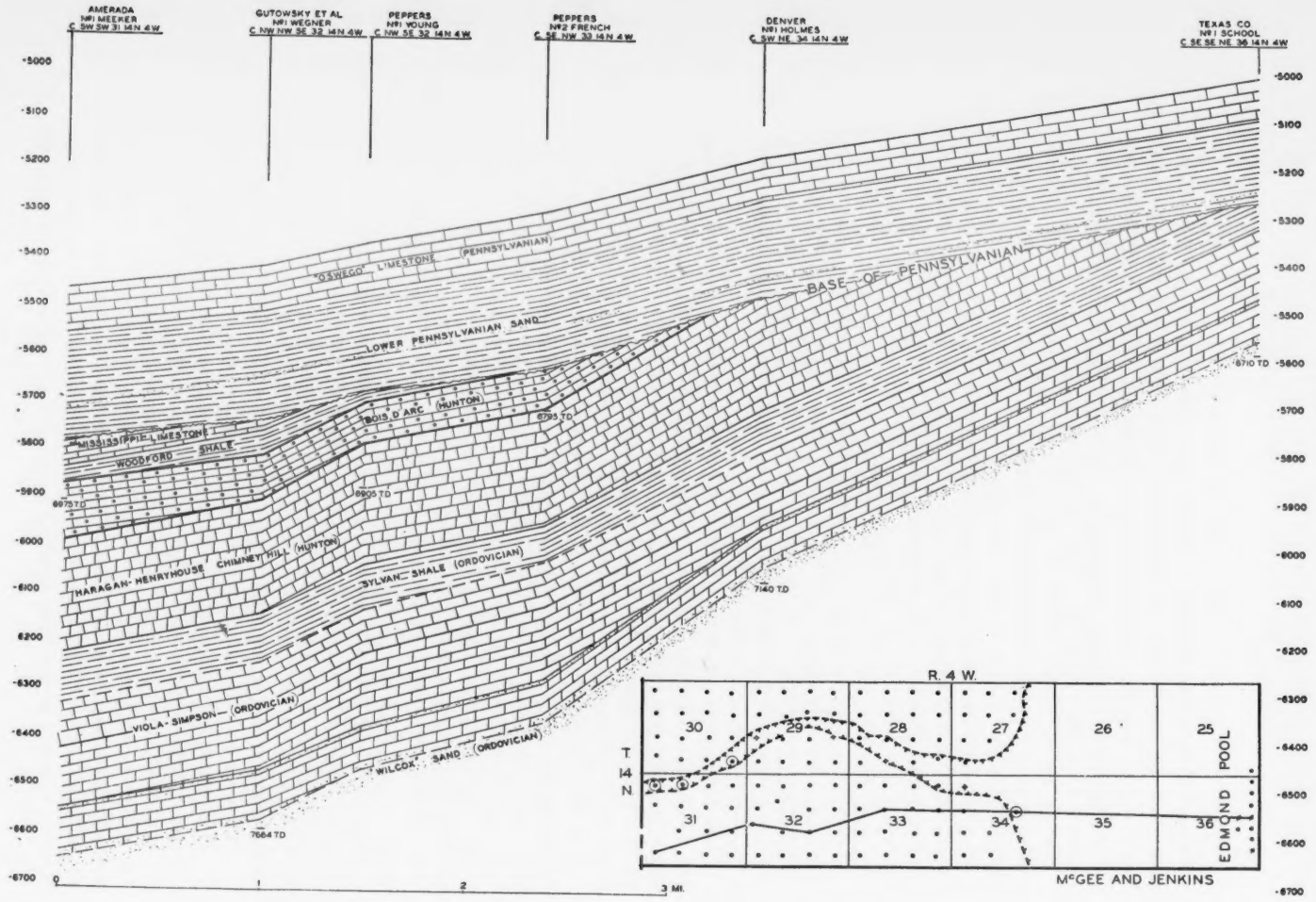
The oil and gas in the West Edmond field accumulated as a result of the wedging-out toward the east and north of the principal producing zone and the west-southwest regional dip of the pre-Pennsylvanian beds, the combination of which produced a very complete and effective trap. The wedge-out of the Bois d'Arc producing zone is shown in Figure 3.

Since the existing structural picture can be described as a monocline dipping west at the rate of about 150 feet to the mile, a study and discussion of the structure of the area must, to be pertinent, not only be directed at determining the structural movements, but also the subsequent periods of erosion and truncation which produced the conditions found in the West Edmond field.

The field lies immediately west of the "Granite" or "Nemaha ridge" line of structures. This series of producing structures is the dividing line between the broad structural plateau of central Oklahoma and the extremely deep structural basin of western Oklahoma. The field lies well up on the west slope of the "Granite ridge," and its origin is definitely linked to the history of the most pronounced of all producing "Granite ridge" structures, the Oklahoma City uplift. The Britton and Edmond structures here are considered to be a part of the Oklahoma City uplift.

The Oklahoma City area began to rise in Ordovician time and continued to be pushed up gently until late Mississippian or early Pennsylvanian time, during which period the upward movement became very pronounced. The uplifting affected an area approximately 25 miles east and west and 40 miles north and south. A major part of the West Edmond field lies within the affected area.

Figure 4 shows the distribution of the beds below rocks of Mississippian age. This map shows that the Oklahoma City structure has been peneplaned until rocks of Arbuckle limestone (Cambro-Ordovician) age are exposed at the crest of the anticline and until beds of "Wilcox" sand, Ordovician age, are exposed at the top of the smaller Edmond fold. Younger rocks are exposed in concentric bands around this central core of older beds. The Hunton limestone, the youngest group of rocks exposed on the pre-Mississippian surface and the formation with which we are concerned in the West Edmond field, has been divided on the map into



EAST - WEST CROSS SECTION
WEST EDMOND FIELD

FIG. 3.—East-west cross section, West Edmond field.

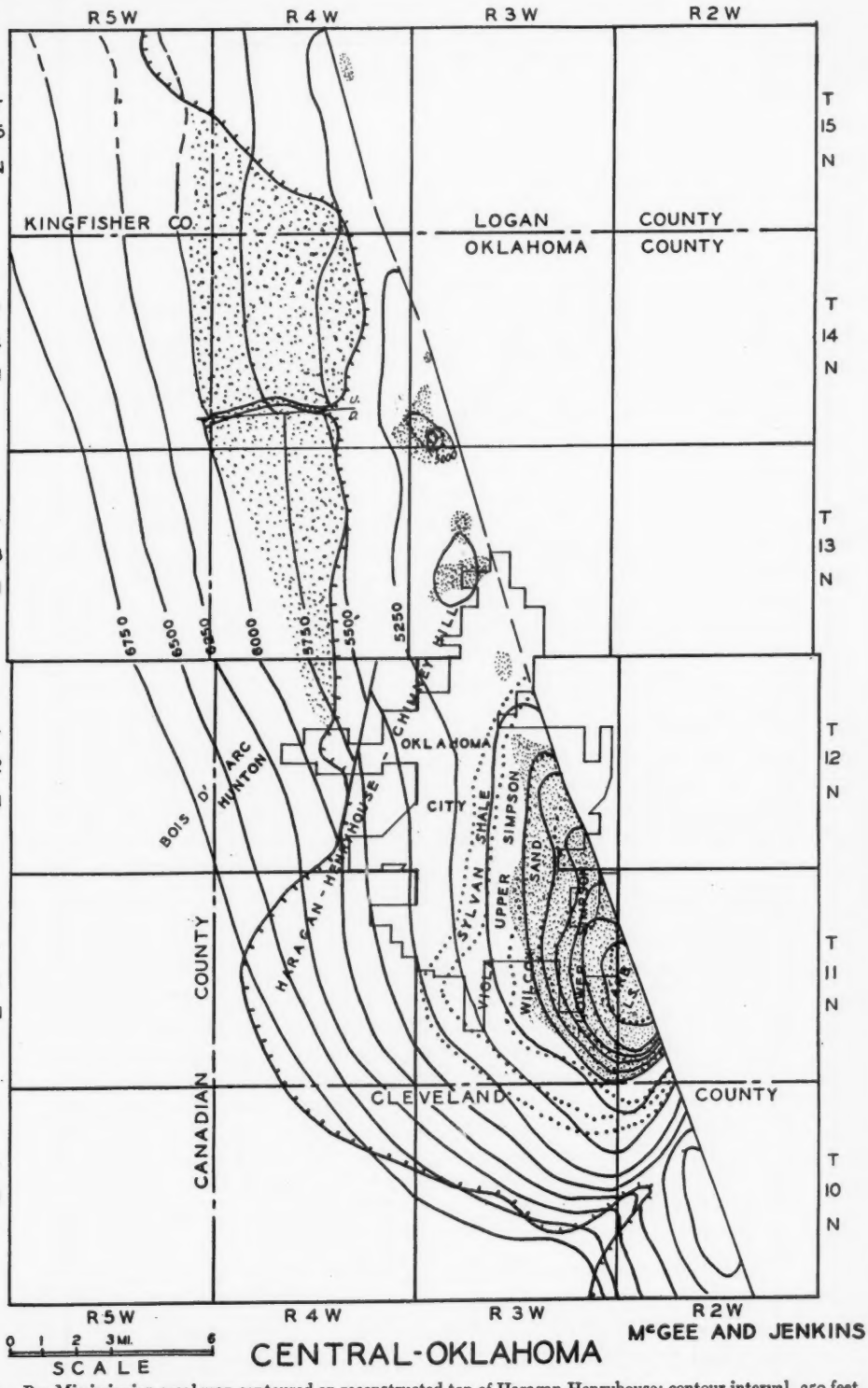


FIG. 3.—East-west cross section, West Edmond field.

FIG. 4.—Pre-Mississippian areal map contoured on reconstructed top of Haragan-Henryhouse; contour interval, 250 feet.

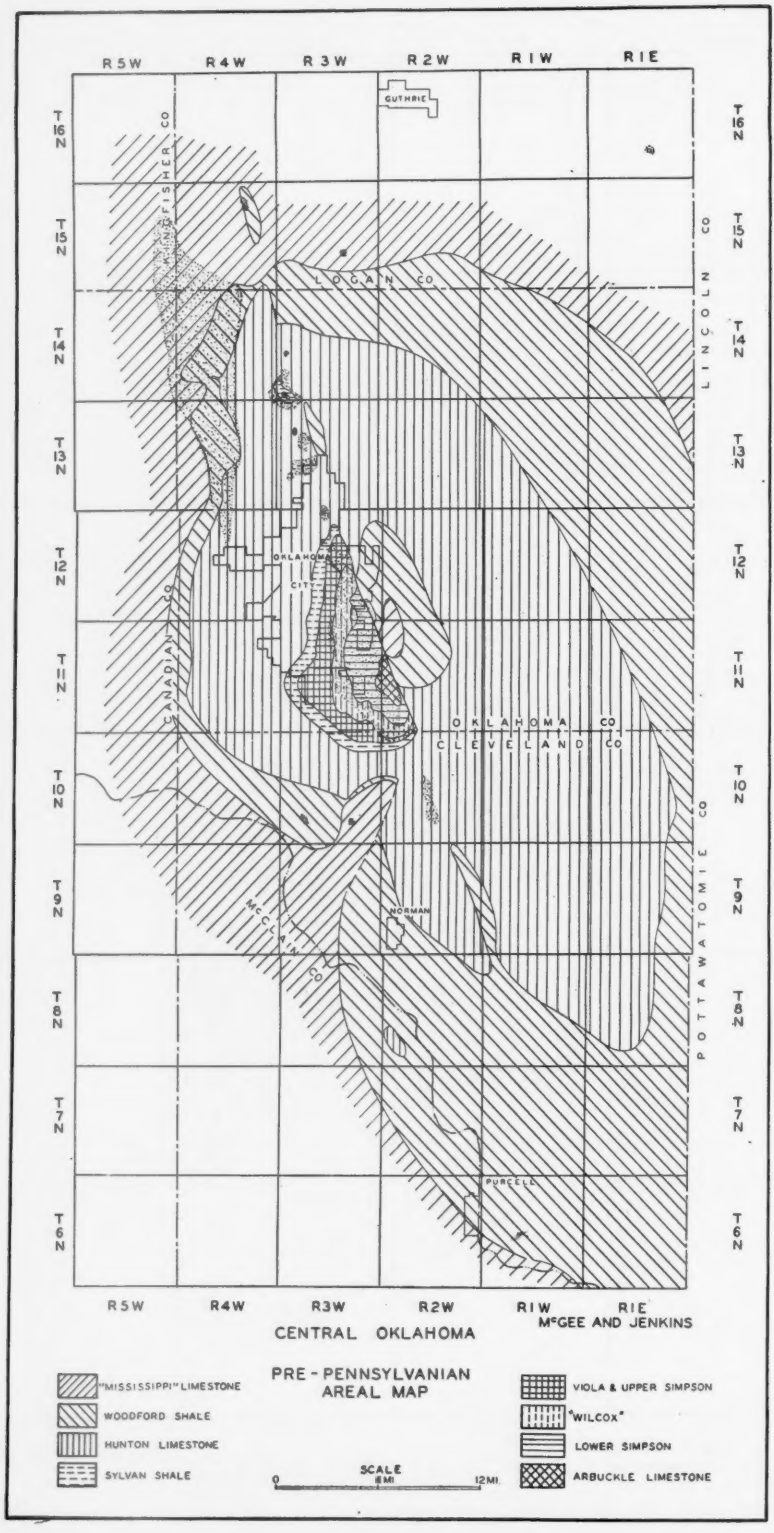


FIG. 5.—Pre-Pennsylvania areal map, central Oklahoma.

two parts—the Bois d'Arc member and the lower members. The map shows clearly the westward-dipping band of Hunton rocks around the west side of the Oklahoma City uplift and along the west slope of the "Granite ridge" fold north of the Oklahoma City area. While the lower part of the Hunton section extends over the north end of the Oklahoma City fold, the Bois d'Arc member wedges out along the west slope. On this map are shown contours on the base of the Bois d'Arc member of the Hunton limestone. The contour interval of 250 feet shows the basinward dip of the beds on the west flank of the "Granite ridge" line of structures. In addition, the slight arch in the Hunton limestone at the north and at the south ends of the West Edmond field is shown. In the south part of the area, immediately west of the Oklahoma City structure, the westward dip steepens and the strike of the contours swings southeast.

Figure 5 is a pre-Pennsylvanian areal map of the West Edmond and Oklahoma City fields and the area adjacent to them.

This map shows the very large area affected by the Oklahoma City uplift; it also shows that by the end of Mississippian time the area of the West Edmond field was relatively low structurally as compared with the Oklahoma City structure. It was probably during this period of late Mississippian or early Pennsylvanian uplifting that the slight arching occurred in the area of the West Edmond field. The tilting toward the south in the West Edmond field undoubtedly came at the same time as the tilting in the Oklahoma City uplift, which is probably late Pennsylvanian in age.

Immediately east of and on the downthrown side of the fault, which bounds the Oklahoma City structure on the east, a full section of Hunton limestone is present. The post-Mississippian uplifting which exposed pre-Pennsylvanian beds at the crest of the structure, and which removed all or a part of the Hunton limestone from a large area around the Oklahoma City uplift, makes impossible an accurate determination of the distribution of the Hunton limestone in pre-Mississippian time. The evidence available indicates that in the hiatus between Devonian and Mississippian time, the north end of the West Edmond field was probably higher structurally and, consequently, probably underwent more erosion and truncation than the area farther south, around and over the present Oklahoma City uplift. This is evidenced by the relatively thin section of Hunton at the north end of the West Edmond field, as compared with a full section in the south end of the field at approximately the same structural level, and a complete section immediately east of the Oklahoma City uplift. The distribution of the pre-Mississippian rocks shown on Figure 4 is, of course, affected by the truncation which occurred at the end of Mississippian time and is not intended to represent a reconstructed surface as it existed at the end of Hunton time. Rather it is a combination of the effect produced by both periods of erosion and truncation.

Figure 6 is a structural map of the West Edmond field contoured on the top of the middle or Haragan-Henryhouse member of the Hunton limestone. The contour interval is 100 feet.

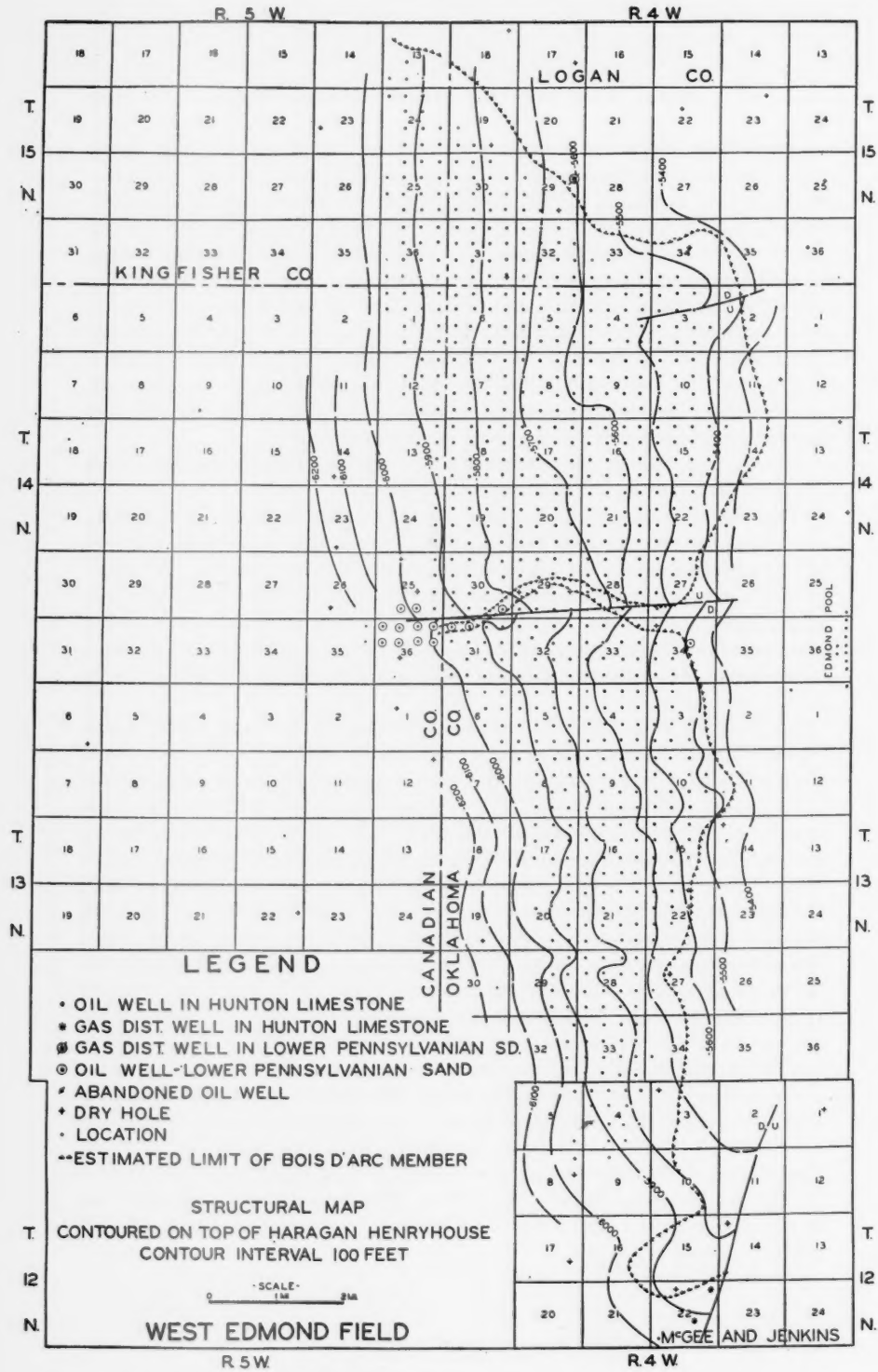


FIG. 6.—Structure map contoured on top of Haragan-Henryhouse, West Edmond field.

The most interesting feature of the map is the fault which crosses the field from east to west in the south part of T. 14 N., R. 4 W. This fault has approximately 100 feet of throw and the upthrown side is on the north. The fault has had little or no effect on the accumulation of oil in the Hunton limestone.

Figure 7 is a map contoured on top of the Bois d'Arc limestone. The contour interval is 100 feet.

The structure as shown is very much like that on the top of the Haragan-Henryhouse member. The dips are slightly flatter due to the eastward thinning of the upper part of the Hunton limestone.

Figure 8 is a map showing the pre-Pennsylvanian areal geology of the field proper.

Figure 9 is a map of the field showing the thickness of the Mississippian limestone and Woodford shale.

This map shows the northwestward thickening of these formations away from the Oklahoma City uplift.

Figure 10 is a map showing the thickness of the Bois d'Arc member of the Hunton limestone. The thickness is shown in intervals of 25 feet.

This map shows graphically the wedge-out of the Bois d'Arc member along the north and east edges of the field and its increase in thickness downdip toward the west and southwest edges of the field. Two interesting features are shown on this map. One is the erosional valley which wanders across the producing area in the south part of T. 14 N., R. 4 W. This valley is undoubtedly the channel of an old stream. The channel cut completely through the Bois d'Arc limestone member in the producing area and in places cut well down into the underlying Haragan-Henryhouse member. Consequently, the stream channel now separates the field into a north and a south part so far as the Bois d'Arc limestone zone is concerned.

Another interesting feature is the area in Secs. 15, 16, 21, and 22, T. 12 N., R. 4 W. from which the Bois d'Arc limestone has been completely removed by erosion. This truncation of the Bois d'Arc limestone is over the crest of a southwest-plunging structural nose. There is probably a thin band of Bois d'Arc limestone, above the West Edmond field water level, around the west end of this denuded area which, if pervious, would connect the oil-producing zone on the north with the area on the south. There have been four wells drilled south of the denuded area, all in Sec. 22, T. 12 N., R. 4 W. Two of the wells, as shown on the map, are gas wells out of the Bois d'Arc limestone—one is a dry hole and one is an oil well in the Bois d'Arc limestone. The two gas wells have a daily open-flow capacity through 2½-inch tubing of approximately 20 million cubic feet each. Each produces approximately 10 barrels of water-white distillate per million cubic feet of gas. These wells are producing gas-distillate at a much lower structural level than many oil wells north of the denuded area. The dry hole may have had a few feet of Bois d'Arc limestone that was impervious. The Haragan-Henryhouse section contained a showing of oil and gas but failed to produce commercially. The oil well in the SW. ¼, SW. ¼ of Sec. 22 encountered the top of

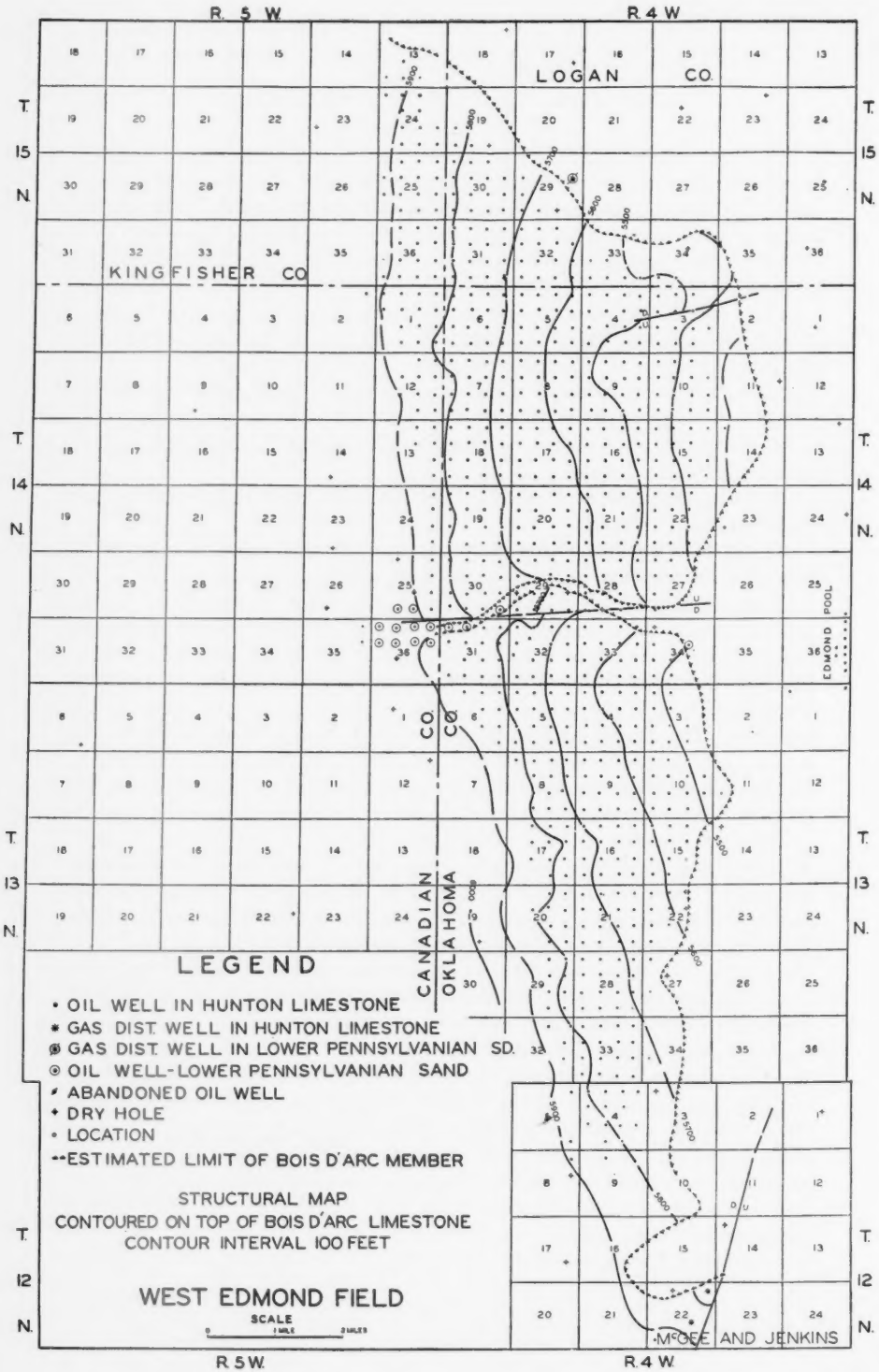


FIG. 7.—Structure map contoured on top of Bois d'Arc limestone, West Edmond field.

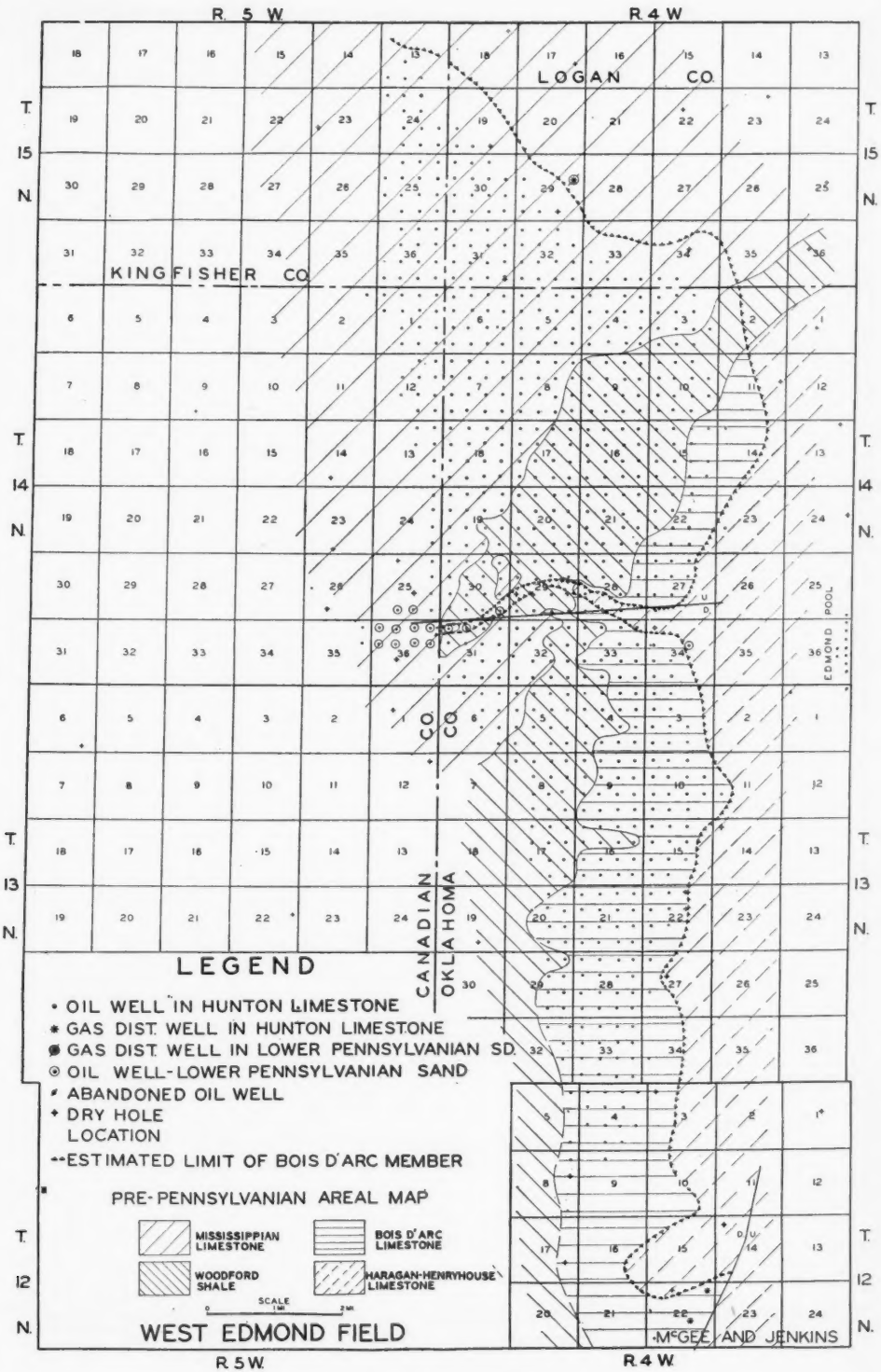


FIG. 8.—Pre-Pennsylvanian areal map of West Edmond field.

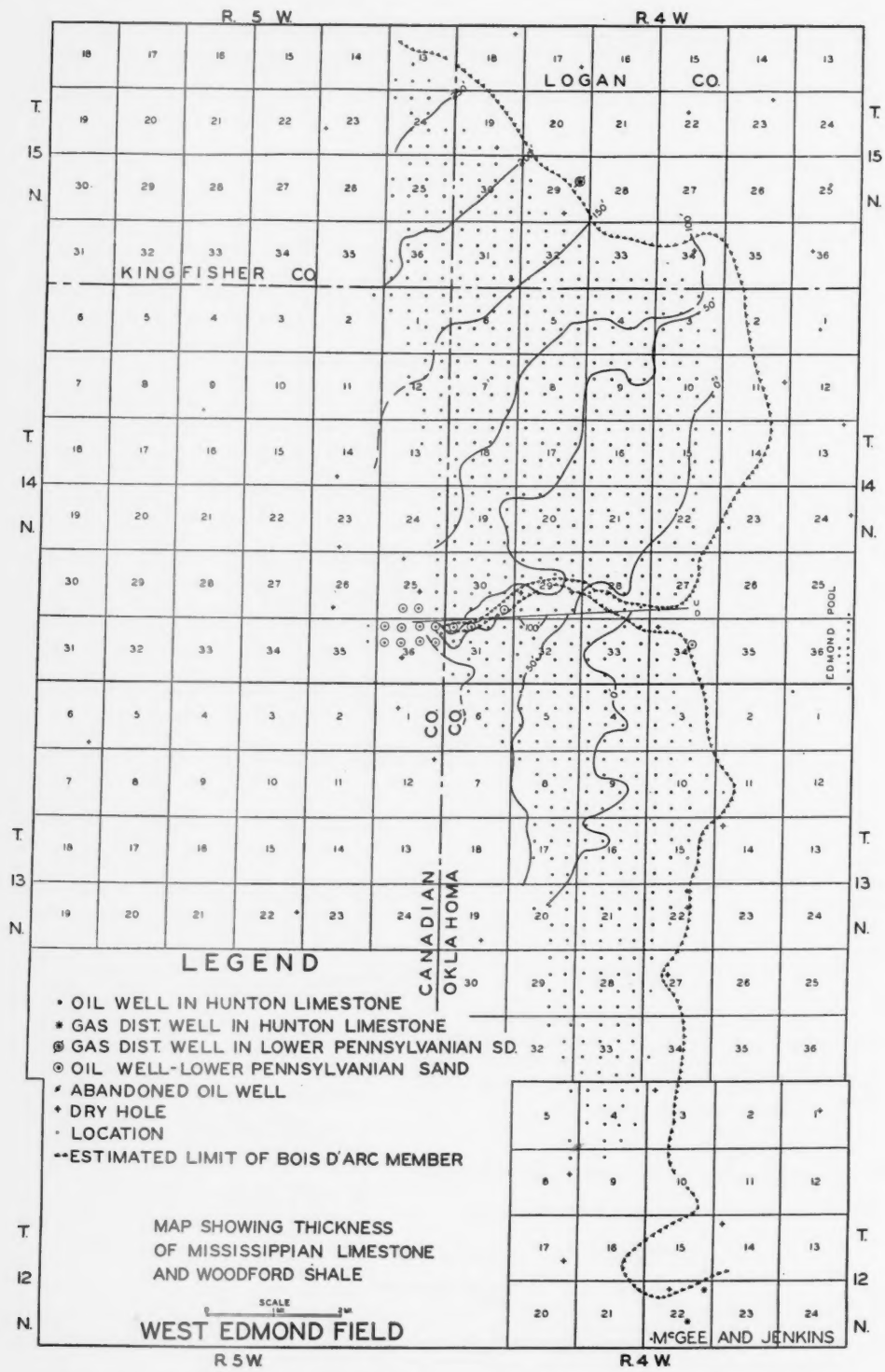


FIG. 9.—Map showing thickness of Mississippian limestone and Woodford shale, West Edmond field.

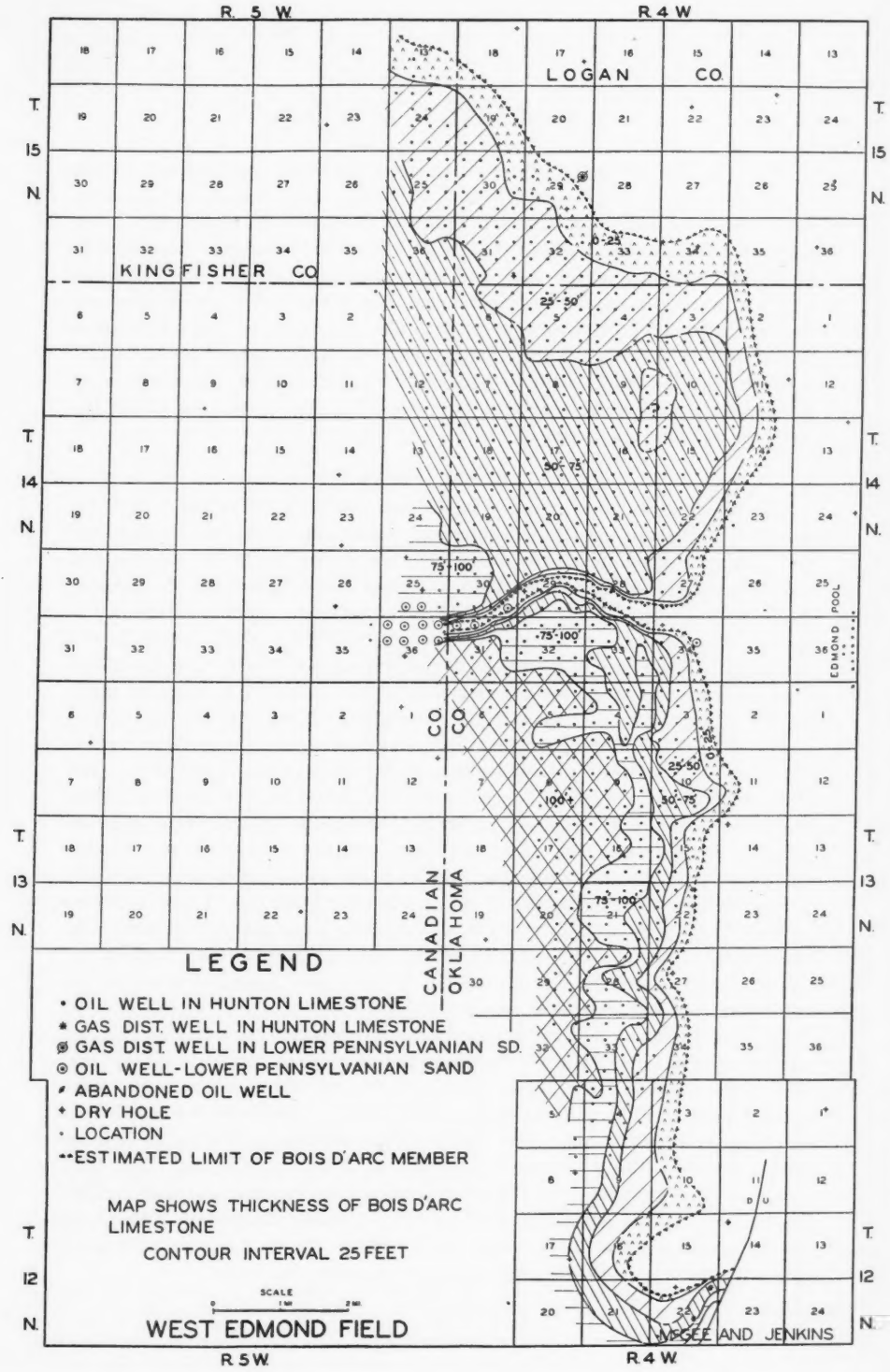


FIG. 10.—Map showing thickness of Bois d'Arc limestone, West Edmond field.

the Bois d'Arc limestone at a subsea depth of 5,929 feet and was drill-stem tested at the minus depth of 5,963 feet. A small amount of oil and a blow of gas were recovered but no salt water. This data indicates the possibility of a slightly lower water level south of the denuded area than north of it. It was drilled deeper into the Hunton section, plugged back and completed for 75 barrels of oil and 200 barrels of water per day. It is possible that a thin band of oil production will connect the area south of Section 15 with the oil-producing zone in the Bois d'Arc limestone north of the area. The presence of gas-distillate at a lower structural level than oil on the north and the relatively high bottom-hole pressures of the three producing wells in Section 22 indicate that there is no connection between the two producing areas.

OIL AND GAS FORMATIONS

The first oil produced in the West Edmond field was from the Bois d'Arc limestone member of the Hunton limestone. Subsequent drilling in the field has developed production in the two other members of the Hunton limestone and in a sand near the base of the Pennsylvanian section in the "Cherokee" shale. Seven hundred and four producing wells had been completed in the field on January 1, 1946. Of this number, 17 are producing from the Pennsylvanian sand, known locally as the "Bartlesville," and 687 are producing from the Hunton limestone.

A production gauge on the discovery well from the Bois d'Arc limestone member, taken April 28, 1943, showed 522 barrels in 24 hours through a 9/32-inch choke. The average initial production of the wells since completed in the Hunton limestone is approximately 1,200 barrels per day. This initial production is after treatment with an average of 1,000 gallons of acid. Initial production of individual wells ranges from a minimum of 25 barrels per day to a maximum of approximately 4,800 barrels a day. The production from the Pennsylvanian "Bartlesville" sand is relatively unimportant, the 17 wells ranging, after being shot with nitroglycerine, from 30 barrels per day to 200 barrels per day. There is an area in T. 15 N., R. 4 W., and T. 15 N., R. 5 W., in which one gas well has been completed in the "Bartlesville" sand. However, drill-stem tests of the "Bartlesville" in other wells, which have drilled to the Hunton zone, have indicated the gas producing zone will extend as far west downdip as Sec. 25, T. 15 N., R. 5 W. This development of gas production in the "Bartlesville" sand at a lower structural level than some of the oil production in this zone is a further indication that several disconnected sand lenses developed at approximately the same stratigraphic position. There are 14 wells producing from the lower two members of the Hunton limestone only. The average initial production of these wells is 200 barrels per day. There are 103 wells producing from both the Bois d'Arc limestone and the lower Hunton. There are 570 wells producing from the Bois d'Arc limestone only. The locations of the Bois d'Arc, the Bois d'Arc-lower Hunton, the lower Hunton and the "Bartlesville" sand wells are shown in Figure 11, which is a well status map of the field as of January 1, 1946.

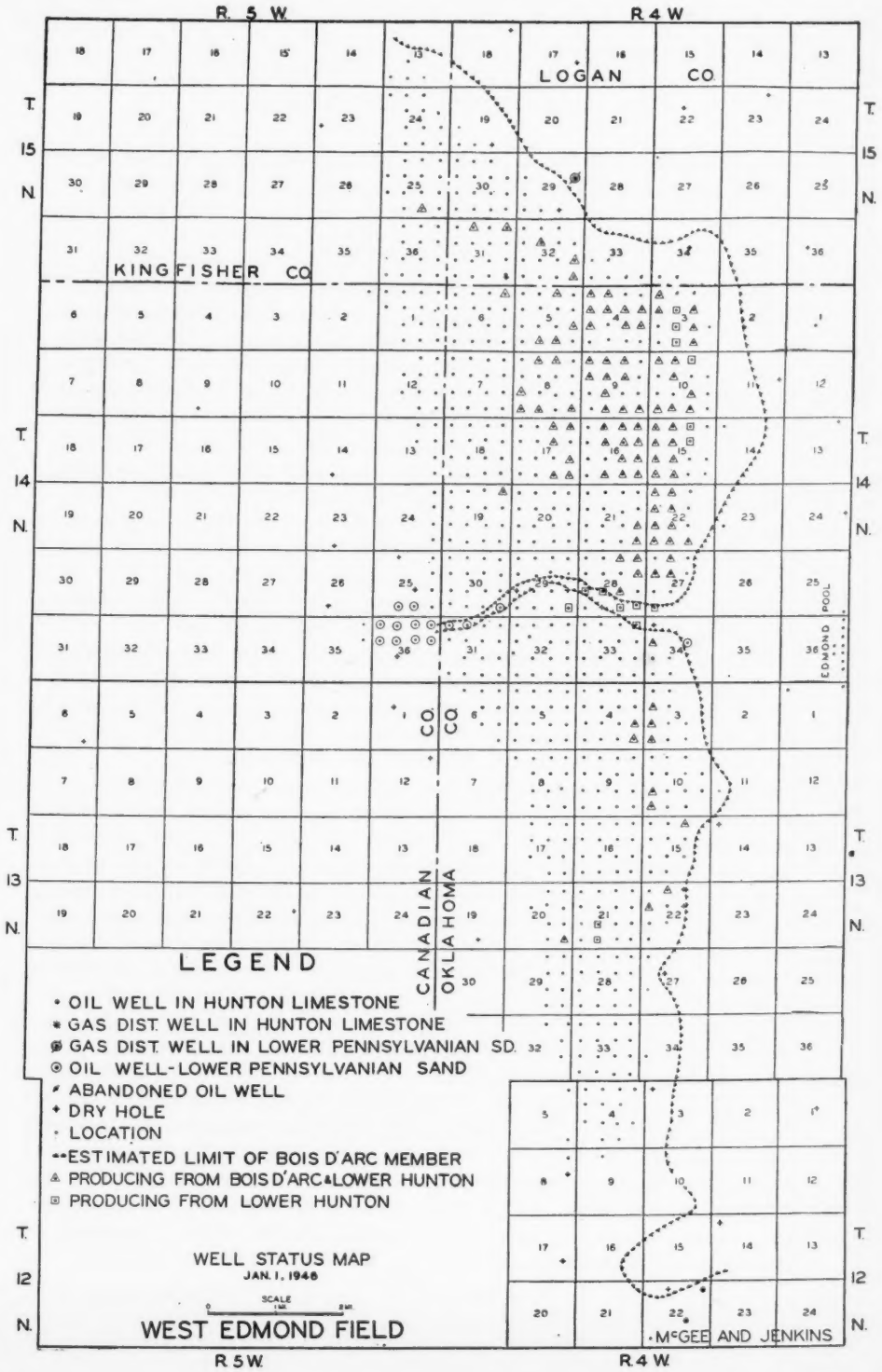


FIG. 11.—Well status map, January 1, 1946, West Edmond field.

All the wells producing from the Hunton limestone are flowing naturally with the exception of 55 wells which are on the pump. These 55 wells are largely on the west edge of the field in the water-producing area.

HUNTON LIMESTONES

Bois d'Arc limestone.—The Bois d'Arc limestone member in the south part of the field consists of 50 feet to 65 feet of coarsely crystalline limestone at the top, with 50 feet to 60 feet of finely crystalline to vugular dolomite with streaks of limestone in the middle, and 15 feet to 25 feet of highly oölitic limestone at the bottom, with a limestone-to-dolomite matrix. Porosity is developed locally all through the section. The exceptional feature of the porosity developed is the fact that it appears to have been produced by means other than weathering at the unconformity surface and some of the porous streaks appear to be void space between crystals and in fractures. In other zones, small solution cavities give the zone a vugular texture. In the north part of the field and along the eastern wedge-out edge where the Bois d'Arc limestone member has been thinned by truncation to less than 30 feet in thickness, porosity and permeability are very poorly developed and, in a few cases, dry holes have been encountered where the thickness of the basal part of the Bois d'Arc limestone is as much as 20 feet.

The total thickness of effective porosity in the Bois d'Arc limestone member for any particular area of the field is impossible to determine on the basis of the information available. In the early development of the field, no attempts were made to core the pay section. When it was realized that there was no data being accumulated on the thickness of the actual pay section within the Bois d'Arc limestone member, several operators cored in an attempt to secure porosity and permeability data. Conventional coring was unsuccessful and, in general, only recovered approximately 60 per cent of the footage cored. Coring with a wire-line core barrel was slightly more satisfactory since it was economical to core shorter sections. While this method did not actually increase the recovery, it did make it possible to determine more accurately what portion of the section cored was recovered and what was lost. Reverse circulation, tried by using a barrel at the top of the drill pipe, recovered approximately 80 per cent analyzable material. In most cases, the material recovered was fragmental and of little value in the determination of porosity and permeability. Several wells were cored by use of a core barrel with stationary inner barrel with a diamond cutter head. The Sohio Oil Company's Lynch No. 4 in the center of the SE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 18, T. 14 N., R. 4 W., cored 56.25 feet of the Bois d'Arc limestone section with a recovery of 84 per cent. The porosity in the section cored and recovered, ranged from a maximum of 18.2 per cent to 0.5 per cent. The Gulf Oil Corporation's Streeter No. 1 in the center of the SE. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 20, T. 13 N., R. 4 W., cored the entire Hunton section with a diamond core head from 6,947 feet to 7,296.4 feet with a recovery of 97 per cent. The porosity of the Bois d'Arc limestone section recovered, ranged from 14 per cent to 0.10 per cent. The diamond cutter-

head method of coring added materially to the expense of drilling and completing the well and, as a result, only a minimum amount has been done. As a consequence, very few data are available on which to base estimates of oil and gas recovery and on which to project pressure-maintenance or secondary-recovery programs. If in the early stages of the development of the field, the operators could have laid out a plan for coring a limited number of wells, selected so as to give a comprehensive picture of the probable producing area, a fairly accurate estimate of reservoir conditions could now be made.

Haragan-Henryhouse and Chimneyhill (both lower Hunton).—The middle Haragan-Henryhouse member and the lower Chimneyhill member of the Hunton limestone have shown porosity in localized areas of the field. The porosity developed may be in any part of the section which ranges from finely granular to coarsely crystalline dolomite. Usually the porosity is of a vugular character, having been developed by the solution of limestone crystals which are embedded in a dolomite matrix. In places, the porosity appears to be from small fracture planes or from voids developed by solution along crystal contacts. While the production from these zones in the productive areas is substantial, they are not now and probably will not be major producing beds.

The only recorded showings of oil and gas in any of the beds above the "Bartlesville" sand in the Pennsylvanian or Permian sections are those in the "Prue" sand. This lack of oil and gas accumulation is to be expected since production from these zones is ordinarily associated with closed anticlinal structures.

LOWER PENNSYLVANIAN SAND

The lower Pennsylvanian sand, known as the "Bartlesville" is widespread in its occurrence around the Oklahoma City uplift, but develops good sand characteristics over only small areas. Generally, it is a very shaly sand to a sandy shale. In the West Edmond field its occurrence is very erratic, most wells showing only a sandy shale zone at this horizon. On January 1, 1946, there were 16 oil wells and one gas-distillate well producing from this zone. Undoubtedly, many wells will find this zone productive when they are plugged back after depletion of the Hunton limestone.

PRODUCTION PRACTICES

COMPLETION METHODS

In the discovery well, the Wagner No. 1, the operators set 7-inch O.D. pipe through the producing zone, bailed the hole dry, perforated in a dry hole, and permitted the well to come in flowing through the casing. Subsequently, $2\frac{1}{2}$-inch tubing was run while the well was flowing. The first few wells completed in the field after the discovery were handled in much the same manner. This practice was soon discontinued because of the hazards involved in running tubing either under pressure or while the well was flowing and, also, because of concern over the possibility of coning water into the producing formation while the well was

flowing wide open through the casing. It soon became the practice to set the pipe completely through the Bois d'Arc limestone member, perforate the pay zone with the hole loaded with mud, then run the tubing, displace the mud with water and then either swab in the tubing or wash the well in with oil. Most wells respond to washing, and the practice of swabbing has largely been discontinued. With most operators it is the practice to let the well flow for a short period in order to clean up the formation as much as possible, then acidize with 1,000 gallons of 15 per cent acid as a wash treatment. Some operators wash with acid after perforating and before unloading the hole. The crystalline limestone in the Bois d'Arc limestone member is soluble and responds very readily to acid treatment. The 1,000 gallon treatment has in most cases been sufficient to start the well flowing at a reasonably high rate of production. The entire Bois d'Arc limestone member and the Haragan-Henryhouse and Chimneyhill members of the Hunton limestone, where productive, are usually perforated with three to four holes per foot, which makes an average perforating job consist of about 200 holes.

A few operators have followed the practice of setting casing on top of the Boid d'Arc limestone member. In some wells the entire section is drilled before the casing is set and sometimes the casing is set and then the section drilled. The wells completed in this way do not appear to show substantial increases in production over those completed by perforating.

CASING PROGRAMS AND WELL EQUIPMENT

Both 7-inch O.D. and $5\frac{1}{2}$-inch O.D. production strings of casing are used in the field. The usual casing program specifies from 300 feet to 600 feet of surface pipe, which may be either $10\frac{3}{4}$-inch O.D. or $9\frac{5}{8}$-inch O.D. casing, depending on whether 7-inch or $5\frac{1}{2}$-inch production string is to be set; then 7-inch O.D. or $5\frac{1}{2}$-inch O.D. casing, either through the Bois d'Arc limestone member or on top of it. No intermediate casing strings are used. The production string of casing averages about 7,100 feet in length. The oil strings of casing are cemented with from 650 sacks to 1,300 sacks of cement. Both $2\frac{1}{2}$-inch and 2-inch tubing are used with most of the wells being completed with $2\frac{1}{2}$-inch. The tubing is generally run to or below the top of the producing formation.

Completion of the wells is a simple problem and the well hook-ups and surface equipment required for the operation of the well after completion are simple in design.

A large majority of the wells in the West Edmond field are being completed by use of stack-type heads and shop-fabricated christmas trees. The trees are 2-inch, $2\frac{1}{2}$-inch and 3-inch, the 3-inch trees being in the majority. Flow lines are 3 inches and 4 inches in diameter. In general the separators are 36 inches by 11 feet, 125-pound working pressure. The tank batteries have been more or less standardized as follows: 80-acre lease, 3 Hi 500-barrel tanks; 160-acre lease, 4 Hi 500-barrel tanks. A few operators have standardized all tank batteries, using 1,000-barrel bolted tanks as follows: 80-acre lease, two 1,000-barrel tanks; 160-acre lease, three 1,000-barrel tanks.

INTERESTING FIELD PRACTICES

Several practices in the field might be of interest. This is probably the first major pool that has been developed by use of bulk cement. In view of the shortage of skilled help during the war period, this has been a boon to the operators and drilling contractors in the field.

Several large acid jobs have been attempted in the field. On one well the casing was set on top of the Bois d'Arc member and the well later treated with 10,000 gallons of acid. The well went on a surface vacuum before the acid job was completed and took a considerable quantity of load oil. After this treatment the well failed to flow and required swabbing for several days before returning to normal production. While these large treatments appear to obtain increases in productive capacity, the increases have apparently not warranted the increased cost at this stage of the production of the field.

It has not been general practice to run caliper logs in the West Edmond field. A number of temperature surveys have been run after cement jobs, and these show a fill-up of approximately 25 per cent can be expected on the average oil-string cement job. There are large shale bodies in the Pennsylvanian section above the Bois d'Arc producing formation, and these have a tendency to wash out badly and, in several places, large concentrations of cement are reflected in these washed out cavities by temperature surveys.

PIPE LINES

There are two oil trunk pipe lines from the field. There are two gas gathering systems in operation in the field. The pipe-line runs for the field by months to the end of 1945 are shown graphically in Figure 12.

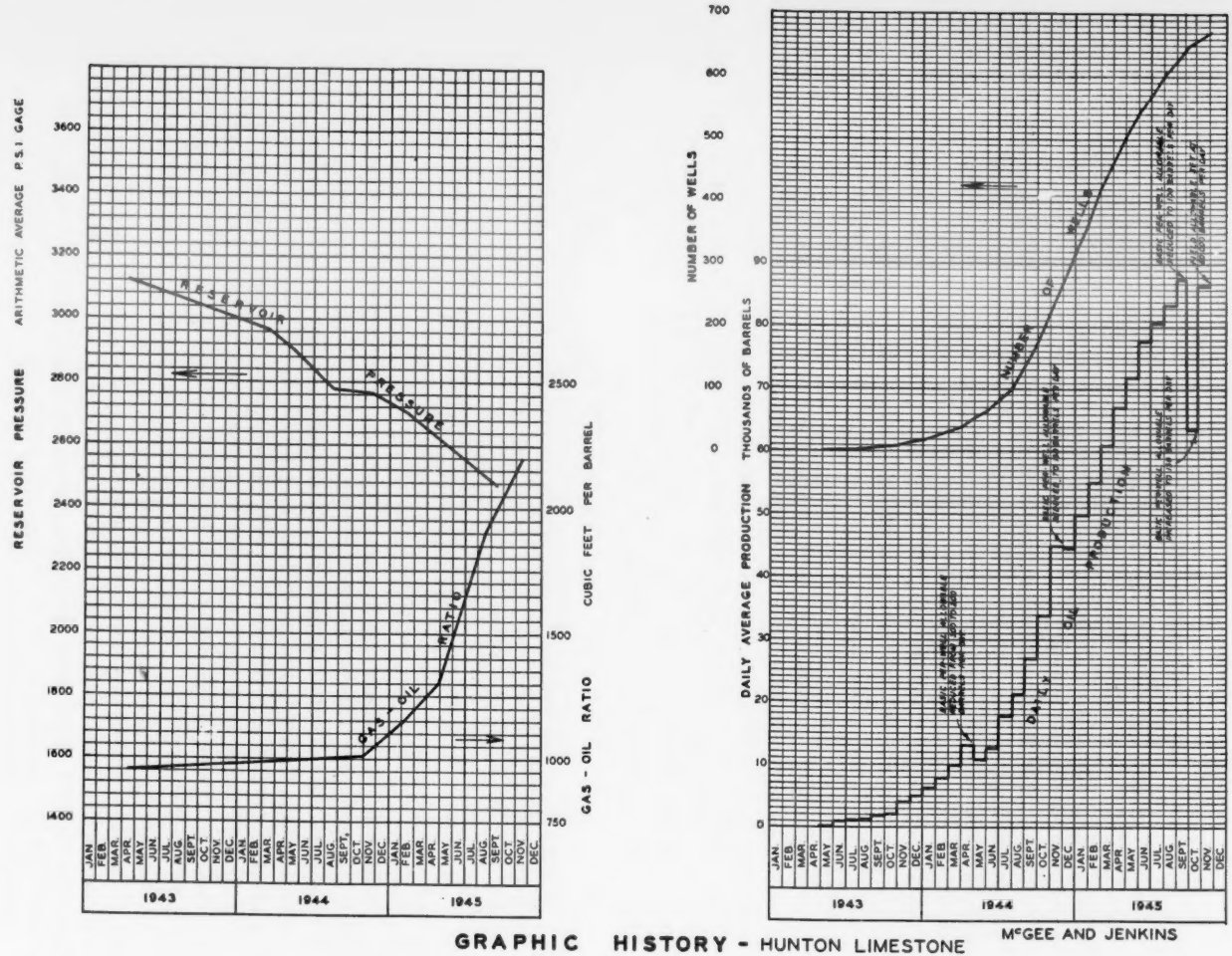
RESERVOIR CHARACTERISTICS

BOTTOM-HOLE PRESSURES

A bottom-hole-pressure test was taken on the discovery well within a month after its completion. The test showed a pressure of 3,110 pounds per square inch, corrected to a minus datum of 5,864 feet. Bottom-hole pressures have been taken on key wells in the field at periodic intervals since this time. The last tests were taken in December, 1945. The 174 key wells tested showed an arithmetic average of 2,360 pounds per square inch, corrected to a minus datum of 5,864 feet. Figure 12 shows graphically the decline of the average reservoir pressure in the field from the date of discovery.

The datum pressures observed in December, 1945, are contoured on Figure 13.

In general, the reservoir-pressure distribution conditions shown on this map are similar in pattern to that observed on previous surveys. The erosional valley and the fault which traverses the central part of the field from east to west are shown on the pressure map for reference. The valley intersects the fault at its west end and the two completely inclose an area in Secs. 28 and 29, T. 14 N., R. 4 W., in which the bottom-hole pressures have shown an exceptionally rapid



GRAPHIC HISTORY - HUNTON LIMESTONE

McGEE AND JENKINS

WEST EDMOND FIELD

FIG. 12.—Graphic history, Hunton limestone.

FIG. 12.—Graphic history, Hunton limestone.

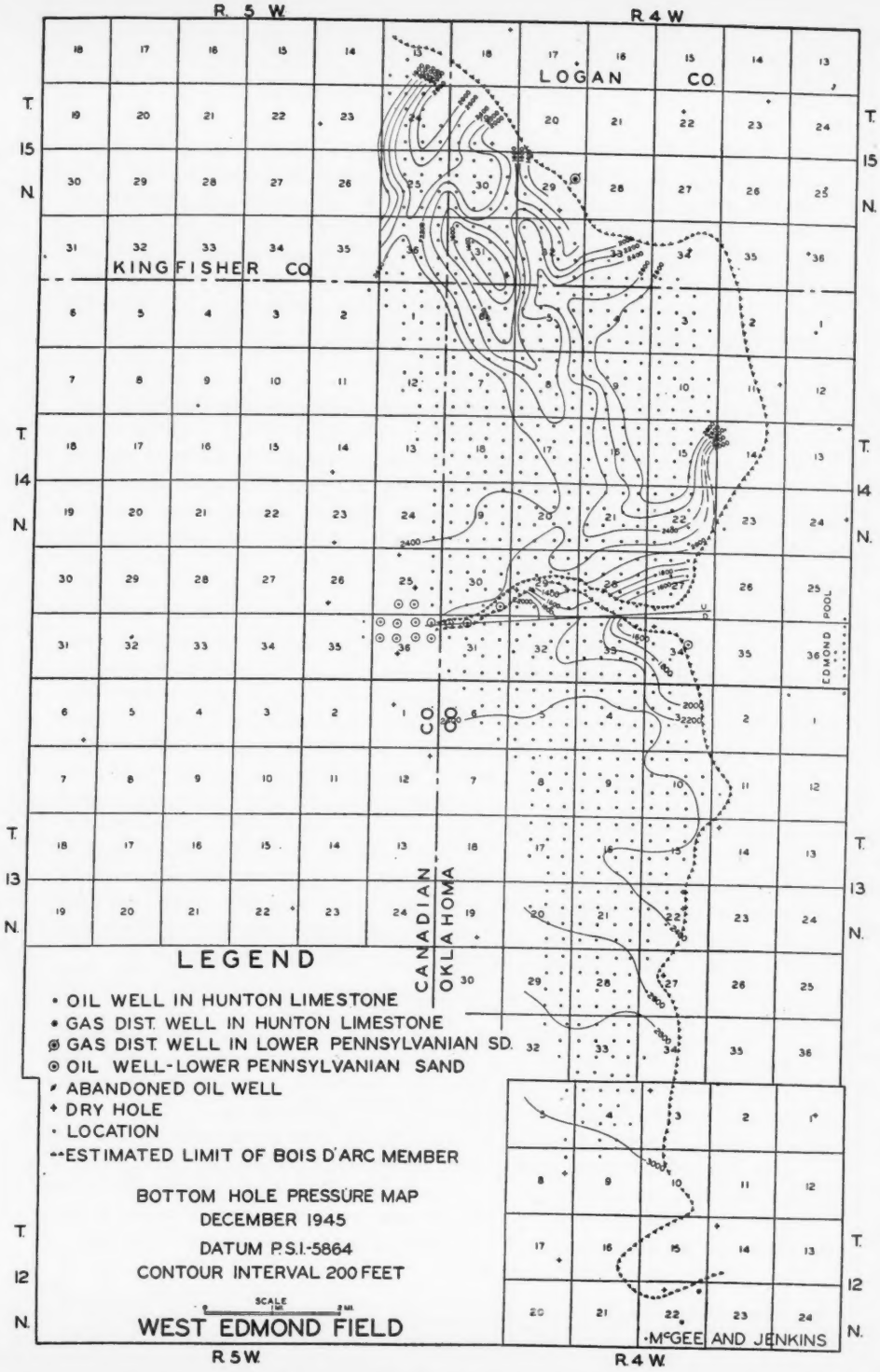


FIG. 13.—Bottom-hole-pressure map, December, 1945, West Edmond field.

rate of decline. This rate of decline can probably be attributed to the lack of free communication of this isolated area with the other producing areas in the field. The other unusually low-pressure areas shown on the map can be attributed to the lack of development locally of porosity and permeability in the producing section. While the north and south parts of the field are separated by the erosional valley, it is too early yet in the history of the field to say what effect this will have on bottom-hole pressures. It is possible that a deferential in bottom-hole pressures will develop in the two separated areas as the reservoir is depleted.

GAS-OIL RATIOS

The rate of decline of bottom-hole pressures, coupled with the history of water encroachment to date, fairly well establishes the West Edmond field as a gas-drive type reservoir. Recently published data on bottom-hole reservoir samples taken by the U. S. Bureau of Mines show the oil in the Hunton limestone producing zones to be slightly under-saturated with gas. This reservoir condition has deferred the development of a large gas cap or caps in the field. Since it is probable no single porous zone in the Bois d'Arc or other producing Hunton sections is continuous over the entire field and since it is probable that there are a number of porous zones with very limited areal extent, an irregular pattern of high-gas-ratio wells would be expected. Such is the case. Prior to January 1, 1946, five field surveys had been made to determine the gas-oil ratios for Hunton limestone wells. The last of these surveys on 630 wells was made in November, 1945. The arithmetic average gas-oil ratio determined from this survey was 2,191 cubic feet per barrel of oil. The ratio had increased from approximately 1,000 cubic feet per barrel of oil in November, 1944. On Figure 12 is shown graphically the trend of gas-oil ratios for the field. An interesting thing about the isolated irregular high gas-oil-ratio areas is that there does not appear to be any relationship between their development and their location structurally. Generally, wells of lower productivity trend toward higher oil-gas ratios and the areas where the oil production has been greatest per unit of effective estimated pay thickness tend to have the highest oil-gas ratios. Figure 14 is a map showing those areas where the gas-oil ratios are in excess of 3,500 cubic feet per barrel of oil.

WATER ENCROACHMENT

On January 1, 1946, there were 105 oil wells in the West Edmond field producing water. There were 7 wells which had previously produced water in small amounts which produced water free oil in December. The oil wells which were producing water on January 1, 1946 are shown on Figure 15.

With a few exceptions, water encroachment from the structurally low west edge has been rather uniform. There are several wells west of the limits of oil production in the field which have reached the Bois d'Arc member and found salt water. Several of the oil wells which were producing water on January 1, 1946, were isolated from the west or water edge of the field and are probably not producing edge or bottom-hole water.

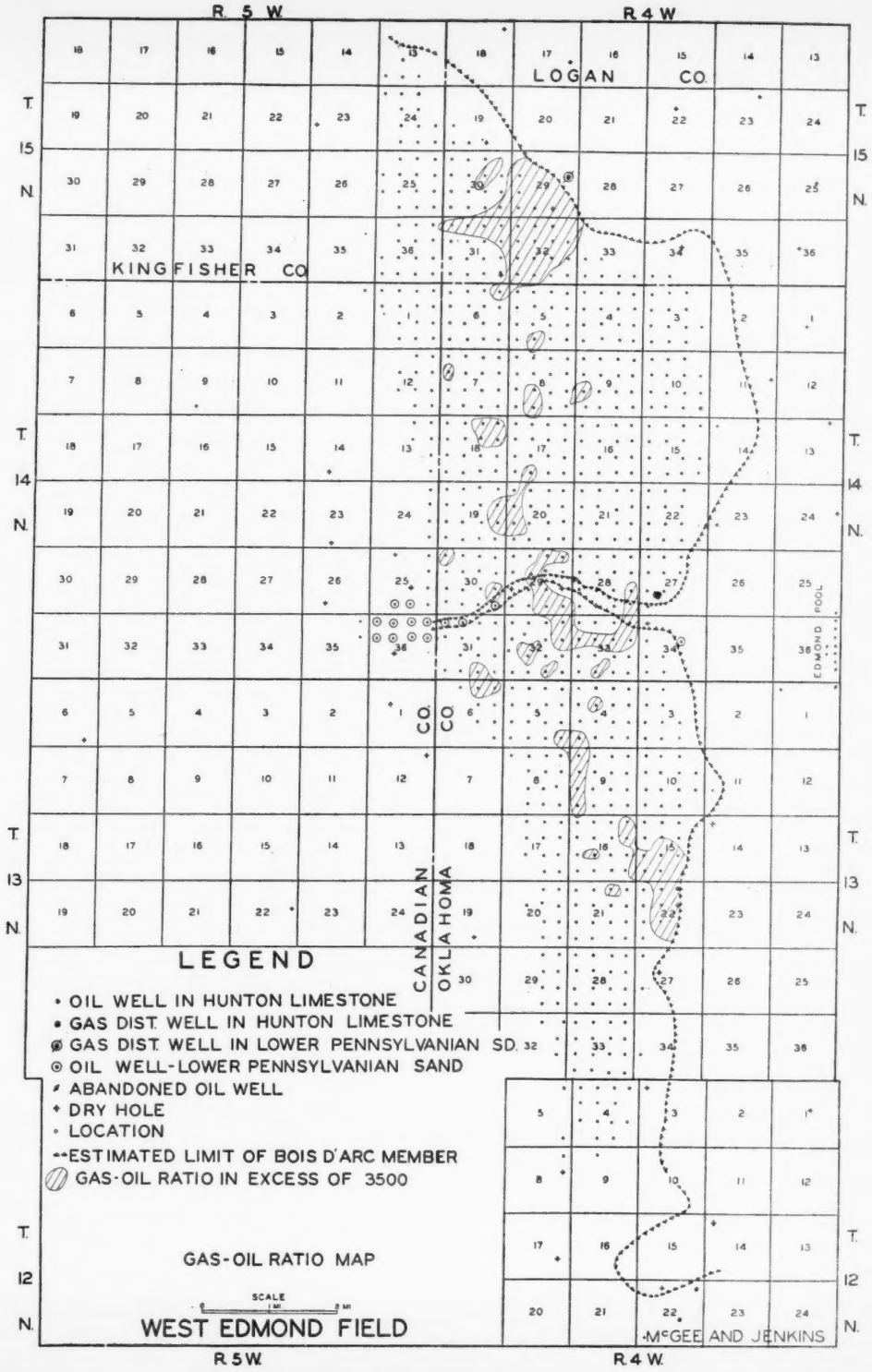


FIG. 14.—Gas-oil ratio map.

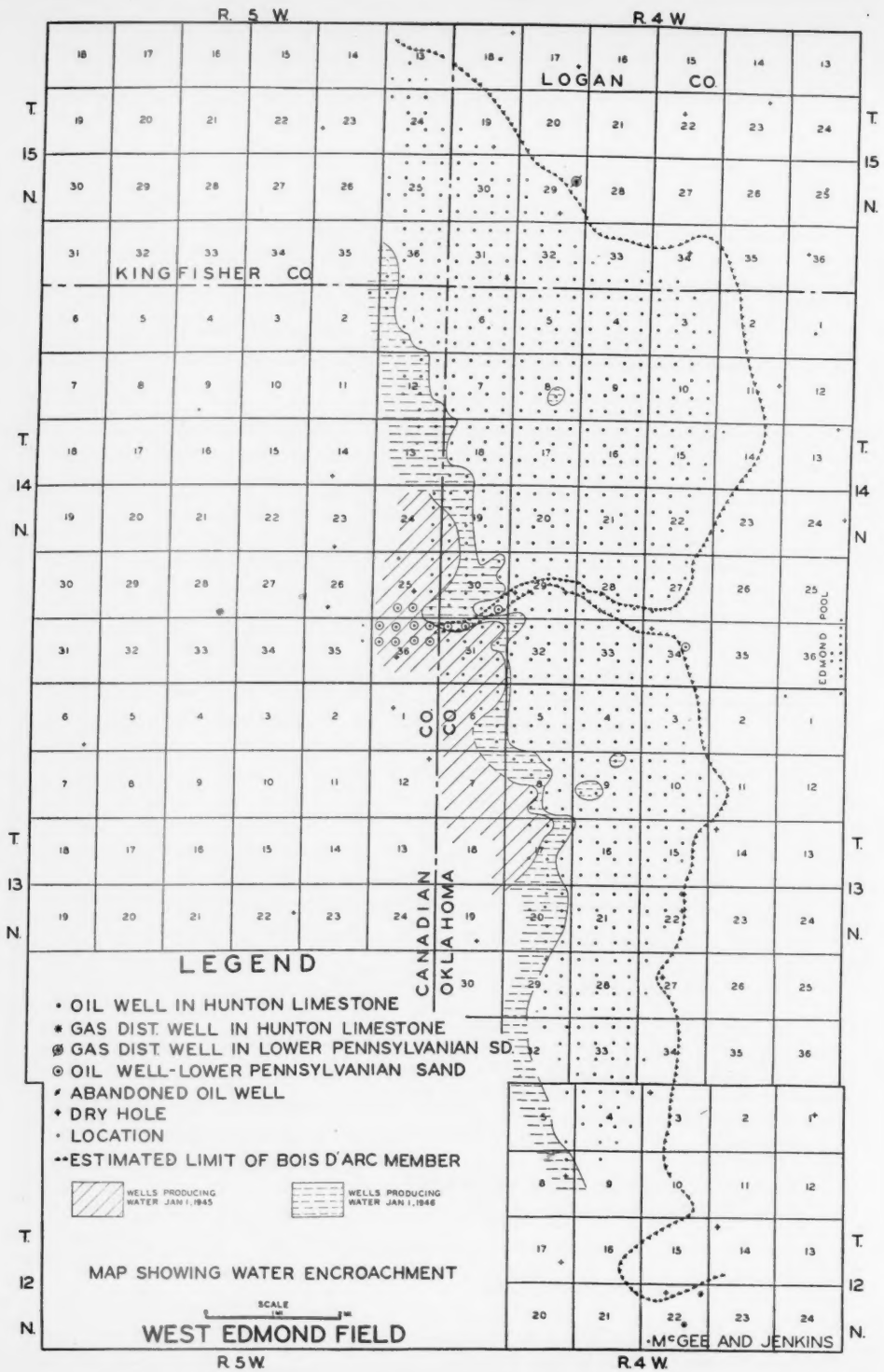


FIG. 15.—Map showing water encroachment, West Edmond field.

The Chudacoff Meeker No. 1, in the NE. ¼, NW. ¼ of Sec. 6, T. 13 N., R. 4 W., was the first oil well in the field to show water. On December 4, 1943, this well was perforated from 7,033 feet to 7,034 feet after setting pipe through the Bois d'Arc member. The well made some oil, but immediately filled with salt water to within 400 feet of the top. It was squeeze cemented, and on December 13, 1943, was perforated from 6,943 feet to 6,985 feet. At this depth it flowed and swabbed 30 barrels of oil with 270 barrels of mud and water in 24 hours. After testing, the well was again squeeze cemented and, on January 5, 1944, perforated from 6,932 feet to 6,969 feet. The well was acidized with 500 gallons and flowed 1,400 barrels of oil in 14 hours with no water. Soon, however, the well began to show water. The testing of this well and data on near-by wells indicate the original water table in that portion of the field south of the erosional valley was between a minus 5,904 feet and minus 5,925 feet. The exact figures on water production in the field are not available. It has been estimated that in December, 1945, the field produced in excess of 225,000 barrels of water. Since the date of first water intrusion the amount of water produced with the oil has shown a steady increase each month. The total amount of water produced per month should continue to increase as additional clean oil wells on the west edge of the field go to water.

As previously stated, it appears now that the principal energy for lifting the oil in the West Edmond field will come from the gas dissolved in the oil itself and not from water intrusion. Undoubtedly, many of the oil wells in the field will be produced to exhaustion without making water.

A majority of the wells in the West Edmond field have completely penetrated the Bois d'Arc member. In the producing area only the 105 wells shown have encountered water. There is, therefore, no water table underlying the pay section of the West Edmond field over a large percentage of its productive area. Only a comparatively narrow fringe along the west edge of the field originally had water below the oil in the pay section.

The producing zones in the Haragan-Henryhouse and Chimneyhill members do not appear to be water-bearing. Since the entrapment of oil and gas in these zones is in localized areas and is probably the result of locally developed, disconnected porous areas and disconnected porous zones, a water level common to them would not be expected.

DRILLING PRACTICES

DRILLING RIGS AND RATE OF DEVELOPMENT

At the end of 1944 there were 120 heavy-duty drilling rigs operating in the West Edmond field. On January 1, 1946, there were 20 rigs in the field. Although the average total depth of the producing wells is 7,100 feet, there have been no difficult drilling problems to overcome. The outstanding features of the drilling campaign were the unusually large concentration of heavy-duty drilling rigs and the remarkable record achieved by the drilling contractors under war-time conditions.

The development of the field started on a rather modest basis—there being only about ten rigs in the field 4 months after the discovery well was completed. As the productive possibilities of the field became more evident, the drilling program was stepped up until by the spring of 1944 the demand for rigs had exceeded the supply. Under the pressure of war-time demand for oil and its products each company attempted to develop its leases as rapidly as possible. Open competition for drilling rigs among the operators in the field soon developed. This great demand for rigs caused many drilling concerns to search their yards for any equipment of sufficient size to drill to 7,100 feet. Many steam rigs that had not seen service for 10 or 12 years were put back into operation; also, many pieces of equipment which had been shelved as obsolete were put into service largely because of the inability of contractors to secure new replacements and repairs. In view of the many types and of the quality of the rigs operated, the difficulty of securing replacement and repair parts, the poor quality and inexperience of many drilling crews and maintenance units, and the critical shortage of drill pipe and tool joints, the drilling record in the West Edmond field was rather remarkable.

The average well in the West Edmond field required in the early development of the field an average of 77 days to move in, drill, complete, and move out. This time has now been reduced to an average of 65 days.

Beds overlying the West Edmond production are flat and no particular difficulty is encountered in drilling straight holes. Most operators require the deviation from vertical to be within 4° and some have a maximum of 3°. There are a few cases of crooked holes in the field, which are largely due to either setting the surface pipe in a crooked hole, or the development of a crooked hole in crowding the drilling in an attempt to make fast time. Most of these crooked holes occur in the soft-digging formations in the Permian above 2,000 feet. In one or two cases, crooked holes in these soft redbeds have later led to key seating.

The number of wells completed each month to the end of 1945 is shown graphically on Figure 12.

The general practice for drilling wells in the West Edmond field is to dig shallow boarded-up cellars, usually 8 feet by 8 feet by 4 to 8 feet deep, erect steel 122-foot derricks on concrete or wooden corners, and dig the usual standard-size circulating and reserve pits. The reserve pits are usually used for circulating until a depth of approximately 5,000 feet is reached. Most holes drilled below the surface pipe are 9 inches in diameter, a few being $8\frac{3}{4}$ inches, where $4\frac{1}{2}$-inch drill pipe is used. On those wells where it is planned to set a $5\frac{1}{2}$-inch oil string of casing, occasionally $7\frac{7}{8}$-inch holes are drilled, using $3\frac{1}{2}$-inch drill pipe. Rock bits are used throughout.

DRILLING MUD

The discovery well was drilled in the winter of 1942–1943 and, during most of its drilling, the weather was exceptionally cold for Oklahoma. Much trouble was encountered with the drilling mud and a caving hole. It was thought at the time

that the caving hole and mud difficulties were largely due to freezing of the mud and a lack of sufficient drilling water to mix mud properly. It was anticipated that the drilling time of 65 days under the surface pipe to the base of the Hunton limestone on the discovery well could be reduced substantially under better operating conditions. As subsequent wells were drilled, it was found that most of the same difficulties with the mud were encountered. These difficulties were found to be caused by a high concentration of calcium salts, particularly calcium sulphate. This high concentration was principally due to contamination of the mud by water from shallow sands and partially to the high concentration of these salts in the surface water being used for drilling. The presence of these salts in the mud causes a low yield of drilling mud per ton of bentonite and, in addition, causes a high water loss. The average well in the West Edmond field requires the use of approximately 25 to 30 tons of bentonite. Some chemicals are used, principally tannic acid, soda ash, and phosphates. The practice is to drill with water and natural mud until a depth of 5,000 feet to 5,500 feet is reached, where the use of artificial mud is begun. The problem of low yield and high water loss has been largely solved in the field by chemically treating the mud with the chemicals previously mentioned, plus sodium silicates. Also, good drilling water is now available and this has helped considerably. The practice is to carry mud 9.7 pounds to 10 pounds per gallon, with a viscosity from 40 to 43 seconds per quart, and with a water loss range of 15 to 20 cubic centimeters.

DRILLING WATER

One of the early drilling problems in the West Edmond field was the water supply. Deer Creek traverses the field from the southwest corner, T. 14 N., R. 4 W., to the northeast corner of the same township. The discovery well was drilled in the valley of this creek and all early development was in the creek valley or nearby. In the spring of 1943 the creek was flowing a large volume of water and all the drilling contractors in the field used it for drilling purposes. Steam rigs soon began to have boiler troubles. Analyses of the water showed a hardness of 40 to 60 grains and a high concentration of calcium sulphate. In the late summer of 1943 this source of water began to fail because of lack of rainfall and several water wells were drilled in the field to the Garber sandstone, found from 200 feet to 700 feet in depth, which is the source of very good water in the Edmond field about 4 miles east. The Garber sandstones were found to contain large volumes of water, but this water, too, was hard and carried about the same large concentration of calcium sulphate as did the surface water. Since there was no other water available in the field, the drilling contractors continued to use what surface water was available, plus water from the wells in the Garber sandstone. As a consequence, the operators of steam rigs found that, in spite of diligent and expensive treating of the water, a battery of boilers would complete only about one well without requiring an overhaul and repair job. Several boiler explosions occurred in the field.

There are now five water systems in the field. Four of these systems bring water from wells drilled to the Garber sandstone, approximately 4 miles east of the field. This water has a hardness of about 2 to 3 grains and is exceptionally good drilling water. Some contractors are still using the available water in small ponds and lakes scattered through the field.

CONSERVATION PRACTICES

STATE REGULATION

The West Edmond field is the only Hunton limestone pool in Oklahoma which has had its production and development closely and efficiently supervised by the Conservation Department of the Oklahoma State Corporation Commission from the time of completion of the first well. The State Conservation Department followed closely the drilling of the discovery well and put into practice applicable conservation measures immediately upon completion of the well.

The Wagner No. 1, discovery well, was drilled on a 10-acre location. On July 1, 1943, the Commission issued its first Order,

> which order defined the boundaries of the probable productive area of the Hunton lime, common source of supply in the West Edmond field, and established 40 acre well spacing and/or drilling units for its development, together with rules and regulations for drilling and operating of all wells therein.

This order has been amended from time to time but the drilling unit has remained 40 acres for oil. The area of gas-distillate production in Sec. 22, T. 12 N., R. 4 W., is permitted 160-acre spacing. The discovery well was given a discovery allowable of 94 barrels per day for a period of one year over and above the regular allowable for the other wells in the pool. On this basis, the Wagner No. 1 well was allowed to produce 394 barrels of oil per day from May 5, 1943, until May 1, 1944. During this period other wells in the field were allowed to produce 300 barrels per day. On May 1, 1944, the daily allowable of the field was cut back to 200 barrels per well per day by order of the Corporation Commission. Additional cut-backs of daily allowable production have been made to meet the market demand within the state, until, on December 1, 1945, the field allowable was set at 80,000 barrels.

Effective with the September, 1944, allowable, the State Conservation Department set up a gas-oil ratio formula that penalized all wells with a gas-oil ratio in excess of 2,000 cubic feet per barrel of oil. In November, 1945, the gas-oil formula was changed, effective January 1, 1946, to permit a full daily allowable to each well that had a gas-oil ratio of less than 3,072 cubic feet per barrel of oil. Wells with gas ratios in excess of this figure were penalized on the same basis as before. In addition, provision was made for the full production of minimum oil wells.

FIELD ENGINEERING COMMITTEE

The West Edmond Field Engineering Association was organized in the summer of 1944 by the operators in the field. The Association immediately acquired

an able and competent petroleum engineer and staff and began to assemble data and make studies of operating practices and well behaviors. The Association operates with the benefit of an advisory committee consisting of one representative from each operator. This committee makes recommendations and suggestions for special studies to be pursued by the Association. The Association has completed several special projects, among which are a survey of the "Bartlesville" sand zone, water production, gas-oil ratios, and bottom-hole pressures. As a matter of routine procedure, the Association collects, records, and reports to members, completion data, including perforating records, acidizing records, production tests, remedial and reconditioning work-over jobs, bottom-hole-pressure tests, gas-oil-ratio tests, productivity tests, detailed data on coring, cores and core analyses, field-well status maps, data maps showing the top, base, and thickness of the producing interval in each well, monthly pipeline runs by leases, water data, where available, and estimated gas production from the field. Engineering reports are issued each 6 months and statistical and supplemental reports each month. The Engineering Association has accumulated complete and accurate data on the West Edmond field and has assembled it in such form as to be readily usable.

FUTURE DEVELOPMENT

As of January 1, 1946, there was a total of 704 producing wells in the West Edmond field. The spacing pattern has been uniformly 40 acres with the exception of two gas-distillate wells; consequently, there are a total of 28,400 productive acres in the field assigned to producing wells as of that date. On the same date there had been a total of 22 dry holes drilled since the discovery, either in the field or immediately around it. Production has been proved over an area approximately 19.5 miles north and south and 2 to $4\frac{3}{4}$ miles east and west.

It is estimated that there are 3,200 acres within the area proved for production but undeveloped on January 1, 1946. Consequently, the total productive area of the field, if completely developed, would be 31,600 acres.

The total accumulated production of oil for the field to the end of December, 1945, is 31,989,388 barrels. The total estimated gas production through the same period is 45,940,930,000 cubic feet.

The discovery of the West Edmond field has led to a re-examination of the oil and gas possibilities of the east and north rims of the western Oklahoma basin. For approximately 200 miles around the rim of this basin, the Hunton limestone is partially or completely truncated. Consequently, there are possibilities for additional discoveries of the West Edmond type accumulation of oil and gas throughout this immense area.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 11 (NOVEMBER, 1946), PP. 1830-1856, 8 FIGS.

HAWKINS FIELD, WOOD COUNTY, TEXAS[1]

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ABSTRACT

This paper presents a summary of the history, geology, and development of the Hawkins oil field, southeast Wood County, Texas, from its discovery in December, 1940, to September, 1945, when regulations of the Petroleum Administration for War were rescinded. Active field development followed completion of the discovery well, and although drilling was restricted by war emergency regulations, 415 oil wells have been completed, producing from the Woodbine formation at an average depth of 4,850 feet.

The Hawkins field occurs on a large northeastward-trending, faulted anticline situated near the north-central part of the East Texas geosynclinal basin. A major fault downthrown toward the northwest and trending northeast-southwest crosses the east part of the field. A pronounced gravity minimum indicates that the field is underlain by a deep-seated salt mass. Structural growth increases progressively with depth to the point where the Woodbine producing formation has structural closure approximating 1,200 feet. The Woodbine oil and gas reservoir, which is 5 miles long and 4 miles wide, underlies 8,774 acres. The estimated ultimate recovery from the oil-productive area, which contains 8,372 acres, is 449,717,500 barrels. Cumulative production to September, 1945, was 43,134,613 barrels. The oil produced from the field is a predominantly asphaltic mixed-base crude with a brownish black color, and the gravity ranges from 16 to 31°. Gas occurs above the Woodbine in the sub-Clarksville sand of the Eagle Ford formation, where porosity is developed.

Extensive coring, together with modern development methods, have made possible an intensive study of the reservoir characteristics which may be unparalleled in any other field. Detailed reservoir information is, therefore, far superior to that available in any other Woodbine field in the East Texas basin. Surface mapping of geologic structure first directed attention to this area, and core-drill information later supplemented and confirmed the earlier surface work. It is noteworthy that until the time of the discovery of the field, the activities of the principal operator were not influenced by geophysics.

INTRODUCTION

In the East Texas embayment, located in the eastern part of the state of Texas, thick salt deposits lying at great depths and probably Jurassic in age are thought to be the source of large salt masses which have caused many of the structures in the region. Some of these structures are due to salt flowage which has penetrated many thousands of feet of sediments forming the shallow piercement-type salt domes. Other structures in the basin have resulted in an arching of the formations through uplift by large deep-seated salt masses. The Hawkins oil field, which is one of the major discoveries in the East Texas basin and the United States during the past decade, occurs on a large northeast-trending faulted anticline of the latter classification. Evidence that the field is underlain by a deep-seated salt mass is strongly indicated by the presence in this area of a pronounced gravity minimum. The Woodbine formation, from which the oil is produced, has been uplifted approximately 1,200 feet above normal. Structural growth, which increased progressively with depth, has continued at least into the lower Clai-

[1] Read before the Association at Chicago, April 3, 1946. Manuscript received, May 23, 1946.

[2] Humble Oil and Refining Company. The writers wish to acknowledge their indebtedness to Monroe G. Cheney for his encouragement in the preparation of this report, to L. T. Barrow and Morgan J. Davis for valuable criticism, and to the Humble Oil and Refining Company for permission to publish the paper. Information furnished by operators of other wells in the field has materially assisted in making the report complete, and the writers gratefully acknowledge these contributions. In addition, thanks are due to Stuart E. Buckley and to many others of the Humble organization who have assisted in analyzing and compiling the extensive field data made available.

borne, as indicated by an arching of the Weches and Sparta beds on the surface.

Extensive data pertaining to structure and reservoir characteristics of the field have been obtained through modern development methods, and as a result detailed reservoir information is far superior to that in any other Woodbine field in the East Texas basin.

The Hawkins oil field is a geologic discovery, since the mapping of surface structure first directed attention to this area, and core-drill information later supplemented and confirmed the earlier surface work. It is noteworthy that until the time of this discovery, the activities of the Humble Oil and Refining Company, principal operator of the field, were not influenced by geophysics. Since the field is not fully developed, this paper presents only a summary of the history, geology, and development from its discovery in December, 1940, to September. 1945, when regulations of the Petroleum Administration for War were rescinded.

LOCATION

The location of the Hawkins field and its geographic relation to other oil and gas fields in the East Texas basin are shown on the index map (Fig. 1). The field, which derives its name from the town of Hawkins, is located in southeast Wood County, Texas, about 17 miles northeast of Tyler. The Gladewater area of the East Texas field is 14 miles southeast, and the Van field is 24 miles southwest.

TOPOGRAPHY AND DRAINAGE

Surface elevations in the Hawkins area range from slightly less than 300 feet along the Sabine River and its tributaries to more than 480 feet above sea-level in the north part. Although a few rather deep narrow creek valleys have developed where the outcropping Weches formation provided a protective cap for the hills, the topography of the area for the most part is characterized by gently rolling sandy hills and valleys.

The area is drained by the Sabine River and its tributaries. A radial, and to some extent circular, drainage pattern is developed in the southwest part of the area. It appears probable that this drainage pattern has been influenced by structure, since it is in this area that the most pronounced arching of the surface formations has occurred.

HISTORY

The attention of the Humble Oil and Refining Company was first directed to the Hawkins area during 1930 as a result of surface mapping of geologic structure by E. A. Wendlandt. This work was done in connection with a surface geologic mapping project covering southern Wood County, Texas, begun during the latter part of 1929 and completed during August, 1930. In view of the small surface closure indicated by this work, no leases were purchased at that time since the structure appeared rather insignificant as compared with other surface features such as Van and Kelsey. However, the discovery of oil at Long Lake in Novem

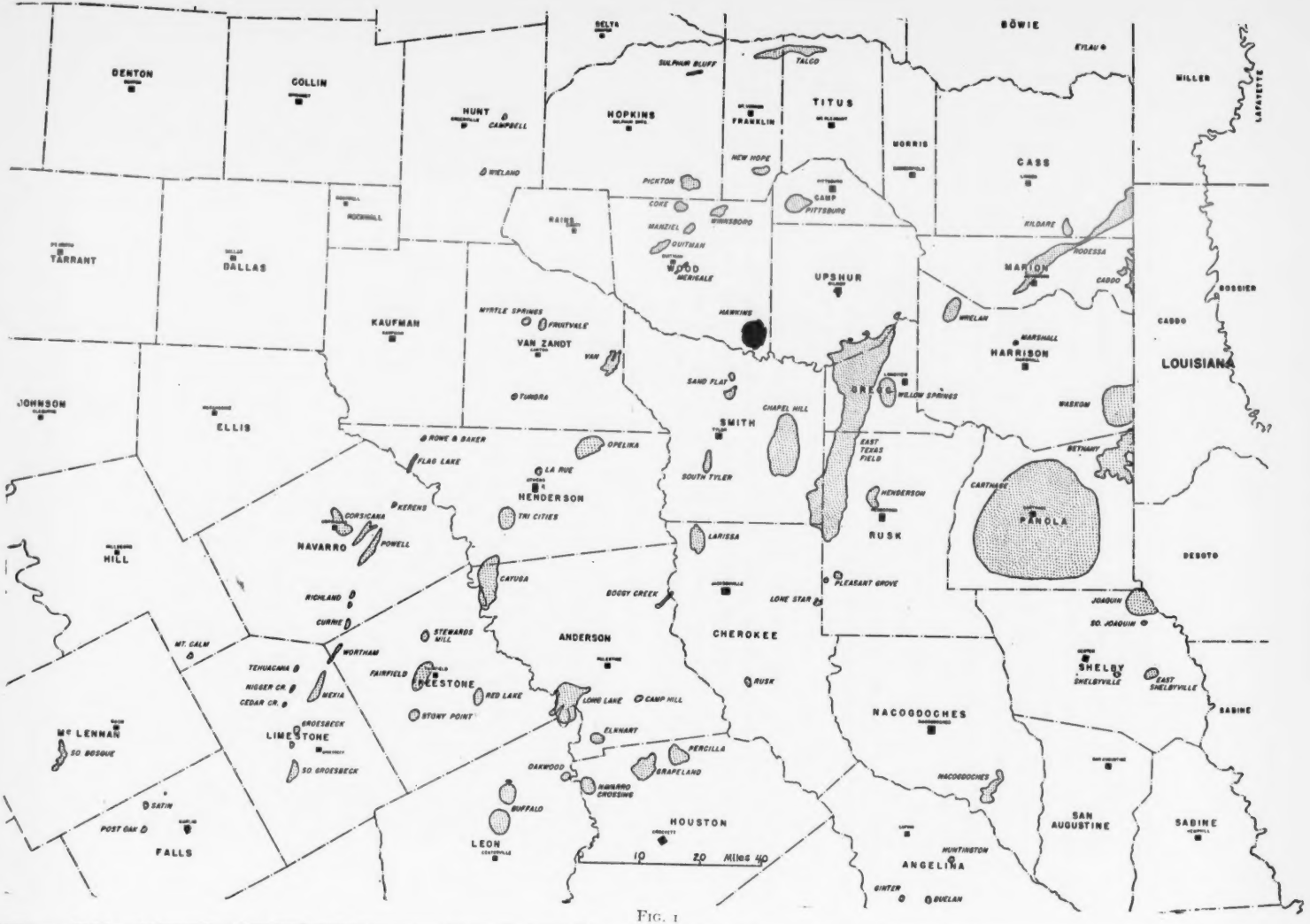

DENTON
COLLIN
HUNT
CAMPBELL
WIELAND
DELTA
SULPHUR BLUFF
HOPKINS
FRANKLIN
TALCO
TITUS
BOWIE
KYLAU
MILLER
LAFAYETTE
MORRIS
CASS
NEW HOPE
PICKTON
CORE
WINNSBORO
CAMP PITTSBURG
MANZIEL
QUITMAN
WOOD
MERIGALE
KILDARE
MODESSA
MARION
CADDO
BOSSIER
UPSHUR
HAWKINS
WHELAN
HARRISON
MARSHALL
LOUISIANA
TARRANT
DALLAS
ROCKWALL
KAUFMAN
MYRTLE SPRINGS
FRUITVALE
VAN ZANDT
VAN
TUNDRA
SAND FLAT
SMITH
CHAPEL HILL
SHREVE
WILLOW SPRINGS
WASKOM
BETHANY
JOHNSON
ELLIS
ROWE & BAKER
FLAG LAKE
OPELIKA
LA RUE
HENDERSON
TRI CITIES
EAST TEXAS FIELD
SOUTH TYLER
HENDERSON
CARTHAGE
PANOLA
RUSK
CORSICANA
KERENS
NAVARRO
POWELL
HILL
LARISSA
DESOTO
CATUSA
BOGGY CREEK
LONE STAR
PLEASANT GROVE
JOAQUIN
SO. JOAQUIN
RICHLAND
CURNE
MT. CALM
STEWARDS MILL
ANDERSON
CHEROKEE
WORTHAM
TEHUACANA
NIGGER CR.
CEDAR CR.
FAIRFIELD
FREESTONE
MEXIA
RED LAKE
LONE LAKE
CAMP HILL
RUSK
SHELBY
SHELBYVILLE
EAST SHELBYVILLE
STONY POINT
GROESBECK
LIMESTONE
SO. GROESBECK
ELKHART
NACOGDOCHES
SABINE
Mc LENNAN
SO. BOSQUE
PERCILLA
OAKWOOD
GRAPELAND
NAVARRO CROSSING
NACOGDOCHES
SATIN
POST OAK
BUFFALO
HOUSTON
SAN AUGUSTINE
SABINE
FALLS
LEON
10 20 Miles 40
HUNTINGTON
ANGELINA
GINTER
DUELAN

FIG. 1

ber, 1933, and at Cayuga in March, 1934, on structures where surface closure appeared to be small, stimulated a renewal of interest in the Hawkins area and prompted the Humble Oil and Refining Company to purchase a lease block during 1934.

During the early part of 1935 the Humble Oil and Refining Company attempted to make a reflection seismographic survey of the area. The results obtained were disappointing, and the project was abandoned without attempting a detailed survey. Subsequent attempts were made to "farm out" the block without success.

In 1937, the Humble Oil and Refining Company moved a core-drill unit into the area and drilled seven core tests to the Navarro group. The results of this work, which was under the supervision of T. J. Burnett, confirmed the presence of structure as indicated by the earlier surface work and also indicated the presence of additional uplift and a considerably larger area of closure. Upon the completion of this work the lease block was materially enlarged, and title-curative work was initiated by the Humble Oil and Refining Company with the idea of drilling a Woodbine test in the block during the early part of 1941.

Before the drilling plans of the Humble Oil and Refining Company materialized, however, Bobby Manziel, an independent operator, drilled his Frank Morrison No. 1 on the northwest flank of the Hawkins structure, which was the discovery well for the field. This well was completed on December 20, 1940, pumping 124 barrels of 18° gravity black oil and 290 barrels of salt water in 24 hours, with production from the Woodbine formation at the total depth of 4,963 feet, plugged back to 4,917 feet.

The second well in the field, F. R. Jackson *et al.* Cobb Heirs No. 1, was drilled in the Hawkins townsite area to the depth of 4,648 feet in the Woodbine formation. Information from this well definitely suggested the presence of a large Woodbine oil reserve as well as the probable presence of a free gas cap in the Woodbine reservoir. This well was completed on December 29, 1940, with an initial production of 122 barrels of 28.5° gravity brownish black oil per hour through a 1-inch choke. Also on December 29, 1940, Bobby Manziel's Lee Bell No. 1, located on the west flank of the structure, blew out while drilling at a depth of 4,360 feet in the sub-Clarksville sand of the Eagle Ford formation. After blowing an estimated 20,000,000 cubic feet of gas per day together with mud and water for about 2 weeks, the well finally cratered and was killed during the latter part of January, 1941. Although the Jackson *et al.* Cobb Heirs No. 1 had previously penetrated gas sand in the sub-Clarksville, the presence of free gas in this section was not recognized until Manziel's Lee Bell No. 1 blew out.

Recognizing the need for immediate safety measures and proration rules to prevent waste in the field, the Railroad Commission, which is charged with oil and gas conservation in Texas, held a hearing in the Hawkins School on January 20, 1941, to develop evidence from which to write a proration order. An order was issued by the Commission shortly thereafter, which provided among other rules

for 20-acre spacing, with exceptions to be granted where necessary to prevent confiscation of property, and for proration of the field with allowable to be based 50 per cent on acreage and 50 per cent on wells. This formula was later modified to provide that no townsite well would receive less than 50 per cent of the allowable of field wells located on 20-acre units.

Development of the field on a 20-acre pattern proceeded rapidly until December 23, 1941, when operations were curtailed by Petroleum Administration for War regulations restricting drilling to units containing not less than 40 acres. On August 5, 1945, the proration formula was temporarily amended to increase the allowable for wells drilled on the 40-acre pattern to prevent inequities. This temporary relief is effective until March 1, 1946. The following tabulation shows the number of completions in the field by years from the date of discovery on December 20, 1940, to September, 1945.

Year	*Completions*			*Abandonments*	
	Dry Holes	*Oil Wells*	*Gas Wells*	*Oil*	*Gas*
1940	0	2	—	—	—
1941	9	243	3	—	—
1942	14	128	—	1	—
1943	9	30	1	3	2
1944	—	8	—	1	1
1945 (1st 8 mos.)	—	4	—	5	—
Total	32	415	4	10	3

Petroleum Administration for War regulations were rescinded on September 1, 1945, and an active drilling program was immediately initiated to complete development of the field on a 20-acre spacing pattern.

STRATIGRAPHY

The known sedimentary formations encountered in the central part of the East Texas basin range in age from Upper Jurassic to lower Eocene. Near the western and northern margins of the basin, highly folded and complexly faulted rocks of Paleozoic age are encountered beneath the unaltered Mesozoic sediments. Although beds at least as old as the Upper Jurassic Eagle Mills salt undoubtedly underlie the Hawkins area, the following discussion is limited to those beds which are well known as the result of field development. With one notable exception which will be described later, all of the wells in the field have either been completed in the Woodbine or have penetrated the uppermost beds of the Washita group.

COMANCHE CRETACEOUS

Washita group.—The Comanche Cretaceous includes several thousands of feet of sediments in East Texas and lies unconformably beneath the Gulf Cretaceous. The Washita group which occurs at the top of the Comanche is composed of a thick series of shales and dense limestones.

Many wells drilled in the central part of the Hawkins field have encountered

impervious Washita sediments above the oil-water contact. A few wells located near the crest of the structure have penetrated such sediments above the gas-oil contact. The upper Washita has been found to consist of gray to brownish fossiliferous calcareous shale, approximately 30 feet thick, resting gradationally on a light gray dense limestone about 180 feet thick. The upper shale appears to be the equivalent of the Maness shale recently described by Bailey, Evans, and Adkins,[3] and the underlying limestone is the Buda limestone as referred to by these authors.

GULF CRETACEOUS

With the close of the Comanche period, some parts of the East Texas basin were gently uplifted and tilted, resulting in the erosion and truncation of a part of the upper Comanche sediments. In the central part of the basin the evidence of a break in sedimentation is less direct. However, an abrupt change in lithologic facies and a pronounced faunal break occurred during this period of time.

Since the Hawkins area is located in the north-central part of the basin, the contact between the Comanche and Gulf series is concordant and abrupt rather than angularly unconformable. The normal sequence of Gulf Cretaceous formations of the East Texas basin is present on the Hawkins structure. Most of the formations display a marked thinning over the top of the uplift due to structural growth. Faulting over the structure is prominent in the lower Gulf formations, but most of the faults are not present at the top of the Gulf Cretaceous. Only a few of the faults extend as high as the lower Eocene formations.

Woodbine.—The Woodbine formation at Hawkins is composed of thick porous, permeable, inter-communicating sands with interbedded gray to greenish shale, mottled red, greenish, brown, and yellow clays and sandy shales, and gray to green bentonitic chloritic sands. Carbonaceous particles are commonly disseminated throughout the formation, and many lenses of gravel and conglomerate are present. The average thickness of the Woodbine formation in the field is about 525 feet. While only approximately 450 feet of Woodbine sediments occur near the crest, slightly more than 600 feet have been penetrated above the oil-water contact on the south flank of the structure. It is estimated that a normal Woodbine section for the Hawkins area would be about 700 feet in thickness, with the result that about 250 feet of thinning is indicated over the crest of the structure.

The Woodbine formation was originally subdivided by R. T. Hill,[4] who designated the upper section as the Lewisville beds and the lower section as the Dexter beds. Inasmuch as these two members are distinct in the Woodbine formation at Hawkins, the original classification designated by Hill is used in this paper.

The Lewisville section of the Woodbine is composed of gray to greenish sandy

[3] Thomas M. Bailey, Frank G. Evans and W. S. Adkins, "Revision of Stratigraphy of Part of Cretaceous in Tyler Basin, Northeast Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), p. 176.

[4] R. T. Hill, "Geography and Geology of the Black and Grand Prairies, Texas," *U. S. Geol. Survey Ann. Rept. 21*, Pt. 7 (1901), p. 292.

shales, redbeds, and ashy chloritic, argillaceous sands of low permeability and high connate-water content. The Lewisville has a thickness of approximately 125 feet near the crest of the structure, while in flank wells near the edges of the field it is more than 200 feet in thickness. Sands constitute about 30 per cent of the total section.

The lower or Dexter section of the Woodbine averages about 350 feet in thickness and is composed of clean porous highly permeable, intercommunicating sands interbedded with sandy shale, redbeds, and shale. This section contains an average of about 70 per cent sand.

The following core record of the Humble Oil and Refining Company's Floy K. Williams No. 1, located in the north-central part of the field, is presented since it is considered a representative field completion. This well was cored continuously from the upper Eagle Ford formation to the upper Washita group, thereby penetrating the entire Woodbine formation.

Depth Cored in Feet	
EAGLE FORD	
4,073–4,091	Recovery 11 ft.
	6 ft. glauconitic sandy shale, thin streaks sand, few fossils, light brown stain and good gas odor
	4 ft. gray shale, few fossils
	1 ft. very fossiliferous, glauconitic sandy shale, light stain. Good gas odor; poor porosity throughout core
–4,111	Recovery 19 ft.
	3 ft. shale
	16 ft. sandy glauconitic shale, fairly sandy in places with little porosity. Light brown stain and good gas odor
–4,129	Recovery 18 ft.
	6 ft. broken shale and sandy shale, fossiliferous. No showing
	1 ft. hard sandy very fossiliferous shale
	11 ft. brittle shale, streaks sandy shale
–4,147	Recovery 14 ft.
	2 ft. hard sandy shale
	12 ft. brittle shale
–4,167	Recovery 17 ft.
	9 ft. very broken shale and hard greenish sandy shale, black dead oil in streaks
	4 ft. shale
	4 ft. greenish sandy shale and shale
–4,187	Recovery 6 ft. shale and greenish sandy shale
–4,195	Recovery 5 ft. brittle shale
–4,215	Recovery 17½ ft. shale, thin streaks of fossiliferous sandy shale
–4,235	Recovery 19 ft.
	9 ft. broken shale and sandy shale
WOODBINE	9½ ft. ashy lignitic green shale. Top Woodbine 4,225 ft. Slight oil stain at contact.
	6 in. ashy sand. No showing
–4,255	Recovery 17 ft.
	1 ft. ashy sand, good odor, lightly stained in streaks
	6 ft. lignitic shale, few streaks of ashy sand, light stain and good odor
	10 ft. ashy lignitic sand, evenly stained, light brown oil, good odor
–4,275	Recovery 20 ft.
	3 ft. ashy sand as above
	1 ft. very hard gray lignitic shale. No showing
	16 ft. ashy sand as above, slightly darker color
–4,294	Recovery 16 ft.
	6 ft. ashy oil-stained sand
	4 ft. ashy lignitic sandy shale, slight stain
	6 ft. lignitic shale. No showing

Depth Cored in feet	
−4,314	Recovery 10 ft.
	4 ft. hard light gray sandy shale. No showing
	6 ft. ashy lignitic sand, light stain and good odor
−4,334	Recovery 18 ft. ashy sand, light stain in places; good odor, poor porosity
−4,354	Recovery 16 ft.
	4 ft. ashy sand, light stain, good odor
	9 ft. broken hard green shale and mottled shale
	3 ft. ashy sand, light stain, good odor. Poor porosity
−4,374	Recovery 19 ft.
	15 ft. ashy sand, light stain, gas odor
	2 ft. green shale
	2 ft. ashy sand, light stain, good odor
−4,394	Recovery 19 ft. slightly ashy sand, stain and odor; good porosity
−4,414	Recovery 12 ft. redbeds
4,414=4,412 ft. Steel line measurement	
−4,430	Recovery 10 ft. broken redbeds, mottled shale and few thin streaks of sandy shale
−4,448	Recovery 16 ft.
	8 ft. lignitic sand with thin streaks of shale. Light stain, good odor, and good porosity
	8 ft. sand. Good porosity, light stain, good odor
−4,466	Recovery 18 ft.
	12 ft. sand. Good porosity, light stain, good odor
	3 ft. hard sandy shale and shale with no showing
	3 ft. sand. Good porosity, light stain, and good odor
−4,484	Recovery 16 ft.
	14 ft. medium-grained sand, light stain at top, grading to darker color toward bottom.
	Bottom 2 ft. bleeding oil sand
Oil-gas contact 4,480 (estimated)	
−4,504	Recovery 14½ ft.
	12 ft. medium-grained saturated oil sand, some fragments lignite
	2½ ft. hard sandy shale, shale and conglomerate; light stain at base
−4,524	Recovery 20 ft.
	1 ft. light gray sandy shale. No showing
	2 ft. slightly ashy oil sand with few thin streaks of shale
	17 ft. medium to coarse-grained saturated oil sand
−4,544	Recovery 20 ft.
	3 ft. medium-grained saturated oil sand
	6 ft. shale and hard sandy shale. No showing
	1 ft. medium-grained oil sand
	10 ft. shale and hard sandy shale. No showing
−4,551	Recovery 6 ft. hard sandy shale with two thin streaks ashy sand, stain
−4,571	Recovery 10 ft.
	3 ft. hard sandy shale
	6 ft. oil sand
	1 ft. hard sandy shale
−4,590	Recovery 17 ft. medium-grained to coarse sand, bleeding oil
−4,609	Recovery 20 ft.
	18 ft. medium- to coarse-grained bleeding oil sand
	2 ft. mottled shale
−4,629	Recovery 18 ft.
	12 ft. redbeds and mottled shale
	3 ft. hard fine-grained ashy sand, no porosity
	2 ft. fine-grained ashy sand, slight porosity, unevently saturated
	1 ft. light green sandy shale
−4,649	Recovery 20 ft.
	2 ft. light green sandy shale, no showing
	6 ft. redbeds
	6 ft. hard ashy sandy shale, slight stain streaks
	4 ft. hard ashy fine-grained sand, stained with dark oil, poor porosity
	2 ft. hard light gray sandy shale, no showing
−4,669	Recovery 17½ ft.
	2½ ft. hard light gray sandy shale, slight stain
	2½ ft. hard fine-grained sand, evenly stained with dark oil, slight porosity
	8½ ft. hard light gray sandy shale, no showing
	4 ft. fine-grained sand, stained with dark oil

Depth Cored in Feet	
−4,689	Recovery 15 ft.
	5 ft. broken sandy shale and sand, bleeding oil, some streaks, no porosity
	6 ft. mottled shale
	4 ft. clean medium-grained sand, bleeding oil
−4,709	Recovery 20 ft. bleeding medium-grained oil sand; bottom 6 in. slightly shaly (dark brown oil)
−4,713	Recovery 3 ft. hard fine-grained shaly sand, streaks shale, some lignite, well stained
−4,716	Recovery 2½ ft.
	1 ft. hard fine-grained tight sand (stained with dark brown oil)
	1½ ft. shale, lignite
−4,732	Recovery 16 ft. hard dark gray sandy shale and shale. A few fossils and small particles of lignite. A number of rather large fossils in bottom 1 ft.
WASHITA	
−4,747	Recovery 5½ ft. hard sandy shale with streaks of shale, few fossils
−4,765	Recovery 1½ ft. hard gritty shale
−4,773	Recovery 19 ft.
	17 ft. hard slightly fossiliferous shale, somewhat sandy in places
	2 ft. hard dense crystalline limestone
4,773=4,777	Steel-line measurement.

Eagle Ford.—The Eagle Ford formation in the Hawkins area is composed predominantly of dark gray laminated fossiliferous shale. Its contact with the underlying Woodbine is marked by an abrupt lithologic change. A hard thin gray argillaceous sandstone is present in many places at the contact. The upper contact of the Eagle Ford with the overlying Austin is unconformable and marked by a phosphatic pebble-conglomerate zone.

During and immediately following the deposition of the Eagle Ford formation, the Hawkins structure experienced a period of active growth. The Eagle Ford varies in thickness from more than 275 feet in wells located low on the flanks of the structure to as little as 115 feet in unfaulted wells on the crest of the structure. It has an average thickness of about 185 feet.

The upper part of the Eagle Ford is sandy, and near the top a sand zone is locally developed which is known as the sub-Clarksville sand. Pebble pockets occur in this sand, which is argillaceous and silty. Both porosity and permeability of the sub-Clarksville are low as compared with the underlying Woodbine sands. Near the crest of the structure the sub-Clarksville sand is very thin or may be absent entirely. Generally, on the lower flanks of the structure the zone is well developed and may contain two or more well developed sand bodies. Evidence of the contemporaneous growth of the structure is afforded by the fact that the sub-Clarksville is either very thin or absent on the upthrown side but is present on the downthrown side of several of the major faults.

Austin.—The Austin formation at Hawkins is divided into two distinct members. The lower member is the Ector chalk tongue which has a remarkably uniform thickness of about 75 to 80 feet. It is composed of hard white chalk that is easily recognized in cuttings while drilling this section, and it therefore forms an excellent marker.

Conformably overlying the Ector is a chalky marl section varying from 100 to 150 feet in thickness, which has a soft thin marly glauconitic chalk at its top.

The slight structural evidence of thinning in both the lower and upper members of the Austin indicates that only a restricted amount of structural growth occurred during Austin time.

Taylor.—The Taylor formation as described in this paper includes those beds which lie below the Pecan Gap and above the Austin as previously described. This definition may include beds which might be classified more properly as Austin in age. However, since the exact relation of these beds with the upper Austin is still in doubt and their lithologic characteristics more closely resemble the Taylor formation, they are included in the latter formation.

Faunal evidence permits the recognition of upper and lower divisions of the Taylor formation in East Texas. The foraminifer, *Vaginulina regina*, is an index fossil which marks the top of the lower Taylor. It ranges downward into the Austin and is commonly scarce at the top of the lower Taylor, a fact which makes it rather unreliable in determining this point. However, the characteristics of the two Taylor divisions generally vary sufficiently to provide reliable electric-log correlations. In the Hawkins area the lower Taylor is composed of an upper gray waxy marl that averages about 200 feet in thickness, a shaly glauconitic sand about 50 feet thick, and a lower shale and marl about 300 feet thick.

The upper Taylor includes those beds lying beneath the Pecan Gap and above the lower Taylor. It is composed of gray calcareous shale and marl. Thin beds of fine-grained glauconitic chalky sandstone occur in the upper part, while a chalky marl marks the base of this section. The average thickness of this member in the field is about 390 feet.

The Taylor was a period of active growth of the Hawkins structure. Many the smaller faults disappear entirely, and the larger faults show a marked decrease in displacement in this formation, which thins markedly over the crest of the structure.

Pecan Gap.—The Pecan Gap formation is composed of gray-white argillaceous fossiliferous chalk interbedded with thin chalky marl. It rests on the upper Taylor and is overlain by the Marlbrook formation. Both contacts appear to be conformable.

The Pecan Gap varies in thickness from 230 feet or more on the flanks of the structure to as little as 110 feet on the crest. The average thickness is about 180 feet. Active structural movement occurred during the deposition of the Pecan Gap.

Marlbrook.—The Marlbrook is gray fossiliferous rather waxy marl which rests with a gradational contact on the Pecan Gap chalk and is overlain by the Nacatoch formation. In common with the underlying Pecan Gap and Taylor formation, the Marlbrook is considerably thinner over the crest of the structure and has an average thickness of about 390 feet. The foraminifer, *Planulina taylorensis*, ranges to the top of this formation.

Nacatoch.—The Nacatoch formation is the lower of two formations belonging to the Navarro group. It is composed typically of an upper chalky sand or sandy

chalky bed about 10 feet thick, two fine-grained fossiliferous porous sand bodies separated by 30 or 40 feet of sandy shale, a fossiliferous shale and sandy shale section, and a lower argillaceous sand and sandy shale about 50 feet thick. All of the sand sections carry salt water. The Nacatoch, with an average thickness of 380 feet, varies in thickness from 480 feet on the flanks of the structure to as little as 325 feet near the crest.

Arkadelphia.—The term Arkadelphia is applied to the upper Navarro marl and shale section which conformably overlies the Nacatoch and occurs at the top of the Gulf Cretaceous series. The unconformity between the Gulf Cretaceous and the Eocene marks its top. In contrast with the thinning noted in the Nacatoch, the Arkadelphia is fairly uniform in thickness, averaging about 125 feet. This fact indicates that the close of the Cretaceous found the Hawkins structure in a state of relative quiescence in contrast to the continued growth and development that took place throughout Taylor and lower Navarro time.

TERTIARY

Eocene.—With the close of the Cretaceous, many of the genera and most of the species which characterized the later stages of this period became extinct and a new fauna, adapted to a changed environment, arose. The formations became less calcareous, and great thicknesses of continental sediments periodically interspersed with marine sediments were deposited in the East Texas basin. The Midway, Wilcox, and lower Claiborne groups are represented by these sediments.

Midway.—The Midway formation at Hawkins is a gray fossiliferous silty shale with a glauconitic marly zone at the base which probably represents the Littig member of the surface section. Some very fine-grained silty fossiliferous sand beds occur near the top of the formation. An unconformity of considerable magnitude marks the base of the Midway, separating this shale formation from the underlying Arkadelphia marl. The upper contact is in some places indefinite because of the gradational nature of the upper Midway and lower Wilcox beds.

The thickness of the Midway decreases from 810 feet in wells located off-structure to 650 feet in normal wells near the crest of the structure. The average thickness for the field is about 740 feet. Structural growth, which generally had become static at the close of the Cretaceous, is thus indicated to have been renewed during Midway time.

Wilcox.—The Wilcox formation is composed of fine- to medium-grained gray non-marine sands interbedded with gray clay, sandy shale, and lignite beds. All of the Wilcox sands contain fresh water with the exception of some sands in the lower part of the formation which contain brackish water. Although a normal Wilcox thickness in the Hawkins area is 950 feet, unfaulted sections near the crest of the structure measure about 700 feet. The average thickness for the field is 755 feet. As a result, structural growth, which was renewed during Midway time, is indicated to have continued during Wilcox deposition.

CLAIBORNE GROUP

The formations of the Claiborne group which are present on the Hawkins structure include the Carrizo, Reklaw, Queen City, Weches, and Sparta. The latter three formations form the outcrop in the Hawkins area, as shown in Figure 2.

Carrizo.—The Carrizo formation, which lies unconformably on the Wilcox, is a medium- to coarse-grained, loose water sand which contains a minor percentage of gray or grown clay. It is about 35 feet thick and contains fresh water.

Reklaw.—The Reklaw formation, which has a thickness of about 175 feet, lies conformably on the Carrizo at Hawkins. It is a marine formation composed of fossiliferous chocolate to brown shale, glauconitic sandy shale, and glauconitic sand.

Queen City.—The Queen City formation, with a thickness of about 350 feet, is composed of thick, fine- to medium-grained non-marine sands and gray to chocolate lignitic clays. It contains fresh water and is the source of most of the well water consumed in the field. As shown by Figure 2, the Queen City crops out in the Hawkins area west of the Weches exposures along the east side of Little Sandy Creek.

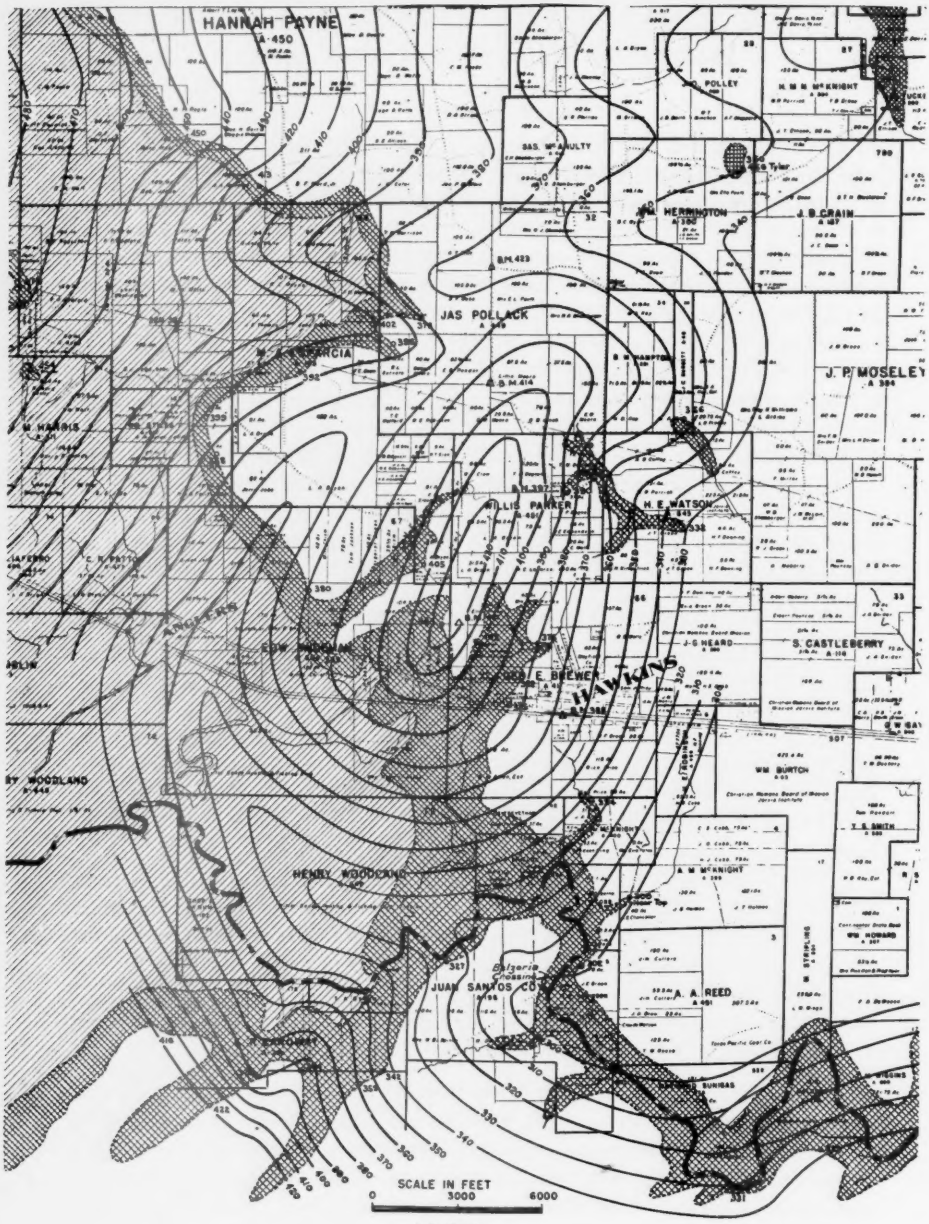
Weches.—The Weches, with a thickness of from 35 to 50 feet consists primarily of dark green glauconite and glauconitic sands interbedded with brown to gray glauconitic clays. The glauconite and glauconitic sands weather locally to form iron ore and ferruginous sandstones. As shown by Figure 2, the Weches outcrops are limited to a narrow band of exposures which extend southward along the east side of Little Sandy Creek and its tributaries to the Sabine River, where exposures occur along its banks. Two Weches inliers are present slightly northeast of the crest of the surface structure. Evidence of late structural growth is indicated by the arching of the Weches beds which afforded surface closure.

Sparta.—As shown by Figure 2, the Sparta exposures are east and north of the narrow band of Weches outcrops and cover a large part of the Hawkins area. This formation is composed of gray fine- to medium-grained sand and interbedded gray and brown clays and is a source of fresh water in many shallow wells. The Tyler greensand, which is the highest zone of the Sparta in the Hawkins area, is a glauconitic sand zone which occurs 106 feet above the Weches. It is present only as a single outlier in the syncline northeast of the surface structure.

STRUCTURE

SURFACE

Late structural movements occurred at Hawkins as evidenced by an arching of the Claiborne formations which form the outcrops. As shown in Figure 2, elevations on the top of the Weches indicate a small anticline with a northeast-trending major axis. The surface structure has about 45 feet of closure, with the crest centering near the common corner of the Edward Wideman, Willis Parker,



SURFACE GEOLOGY AND STRUCTURE OF HAWKINS AREA WOOD COUNTY, TEXAS

FIG. 2

and George Brewer surveys. Faulting is not apparent in the surface formations. The area of surface closure is considerably smaller than the productive area of the field and centers slightly southwest of the crest of the structure as mapped on top of the Woodbine formation.

SUBSURFACE

Core-test structure.—Data derived from seven core holes drilled into the Cretaceous (Navarro group) by the Humble Oil and Refining Company in the Hawkins area furnished the first clues that structural relief increases with depth and that the areal extent of the subsurface structure is considerably larger than indicated by surface control. Figure 3 shows the results of the core-drill work, which indicate closure of approximately 200 feet on top of the Cretaceous. Subsequent drilling in the field has revealed that the closure is more than 275 feet and that the area of closure extends farther east than indicated on the early core-drill map. A small amount of faulting has been recognized in the Navarro from the later field development.

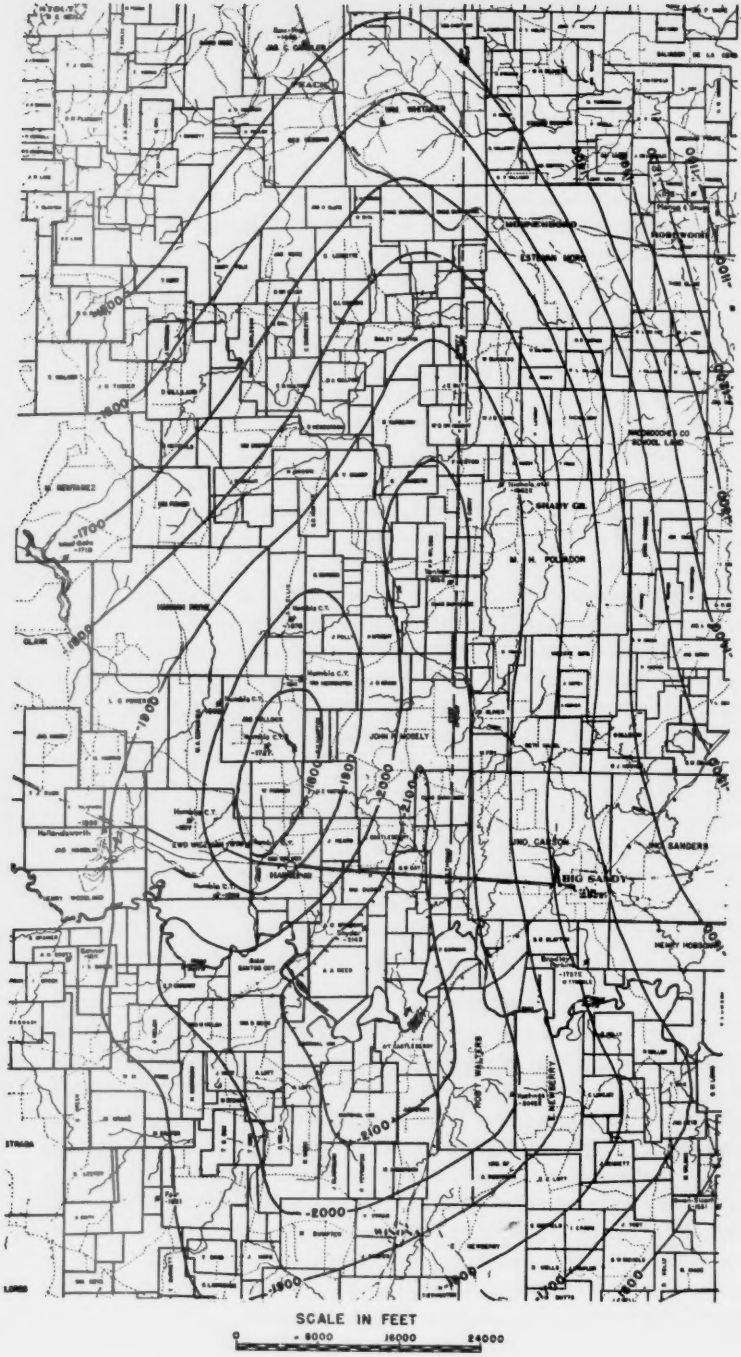
Woodbine structure.—Figure 4 is a structure map of the Hawkins anticline contour on top of the Woodbine formation at 100-foot intervals. Structural growth during Gulf Cretaceous and Tertiary time has resulted in the Woodbine reservoir sands being uplifted approximately 1,200 feet above normal. Coincident with the upward movement, tensional strains developed in the formations across the crest of the structure. These strains were relieved by faulting, resulting in the development of a complex graben system parallel with the major axis of the anticline. A secondary fault trend also developed roughly at right angles to the major axis. The displacement of the faulting, being proportional to the tension which in turn is proportional to the uplift, is greater in the older formations.

Figure 5 is a northwest-southeast cross section which shows the relation of the vertical uplift to the horizontal extent of the structure. The increase with depth in the displacement of the faults and the thinning of the various Cretaceous formations over the structure are both illustrated on this section.

PROSPECTS FOR DEEPER PRODUCTION

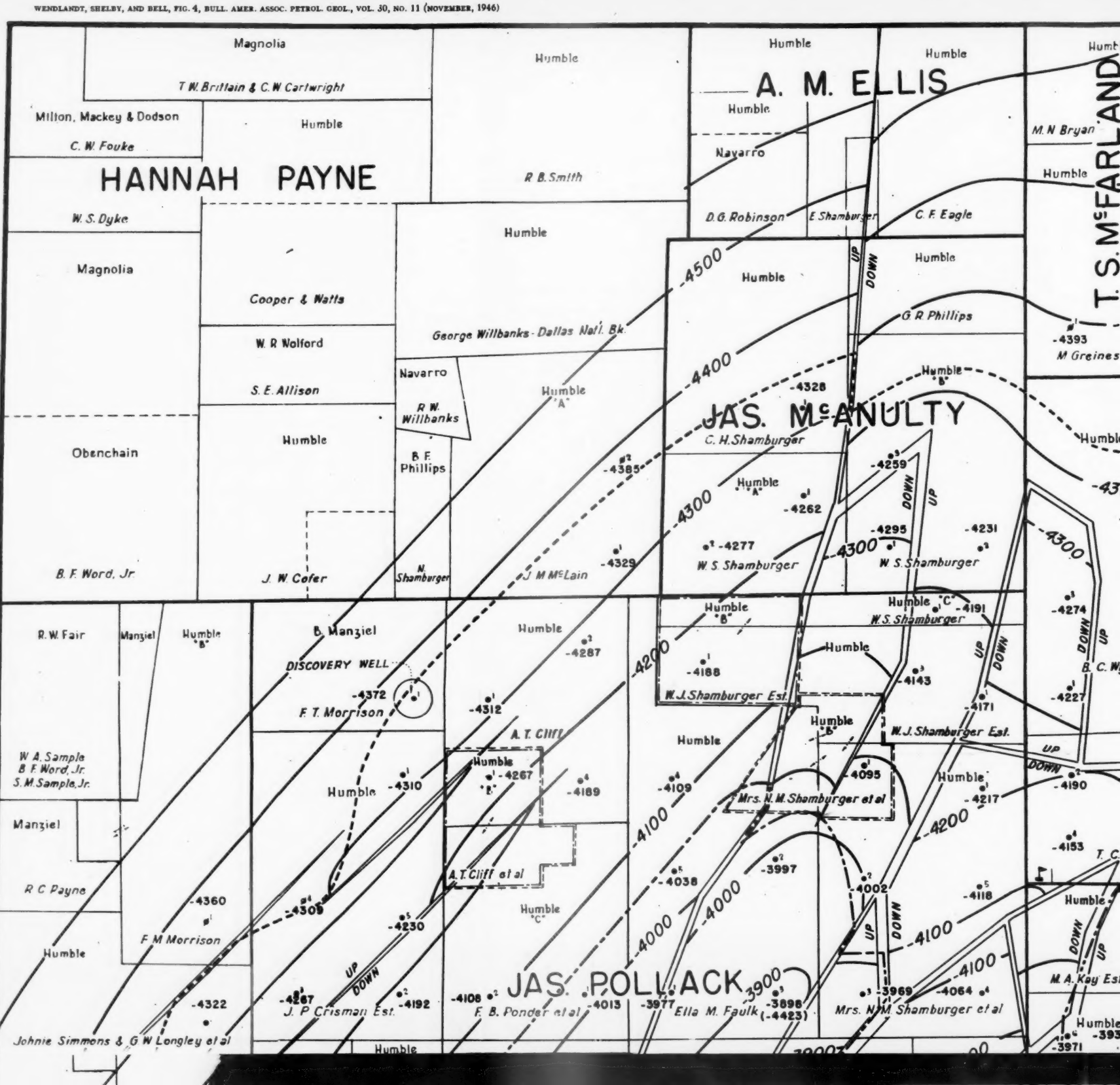
The only well drilled on the Hawkins structure to date which has penetrated beds older than upper Washita is Rogers Lacy and Smith Price's Gladys Maberry No. 3. This well is located in the S. Castleberry Survey near the east edge of the field. Before completion as a Woodbine oil producer, it was drilled to the total depth of 6,535 feet, penetrating 46 feet of the upper Glen Rose formation. The formations of Washita age encountered by this well were 831 feet thick, and those of Fredericksburg age were 238 feet thick. Although control is meager, the combined thickness of the Washita-Fredericksburg appears to be considerably less than would normally be expected in this area.

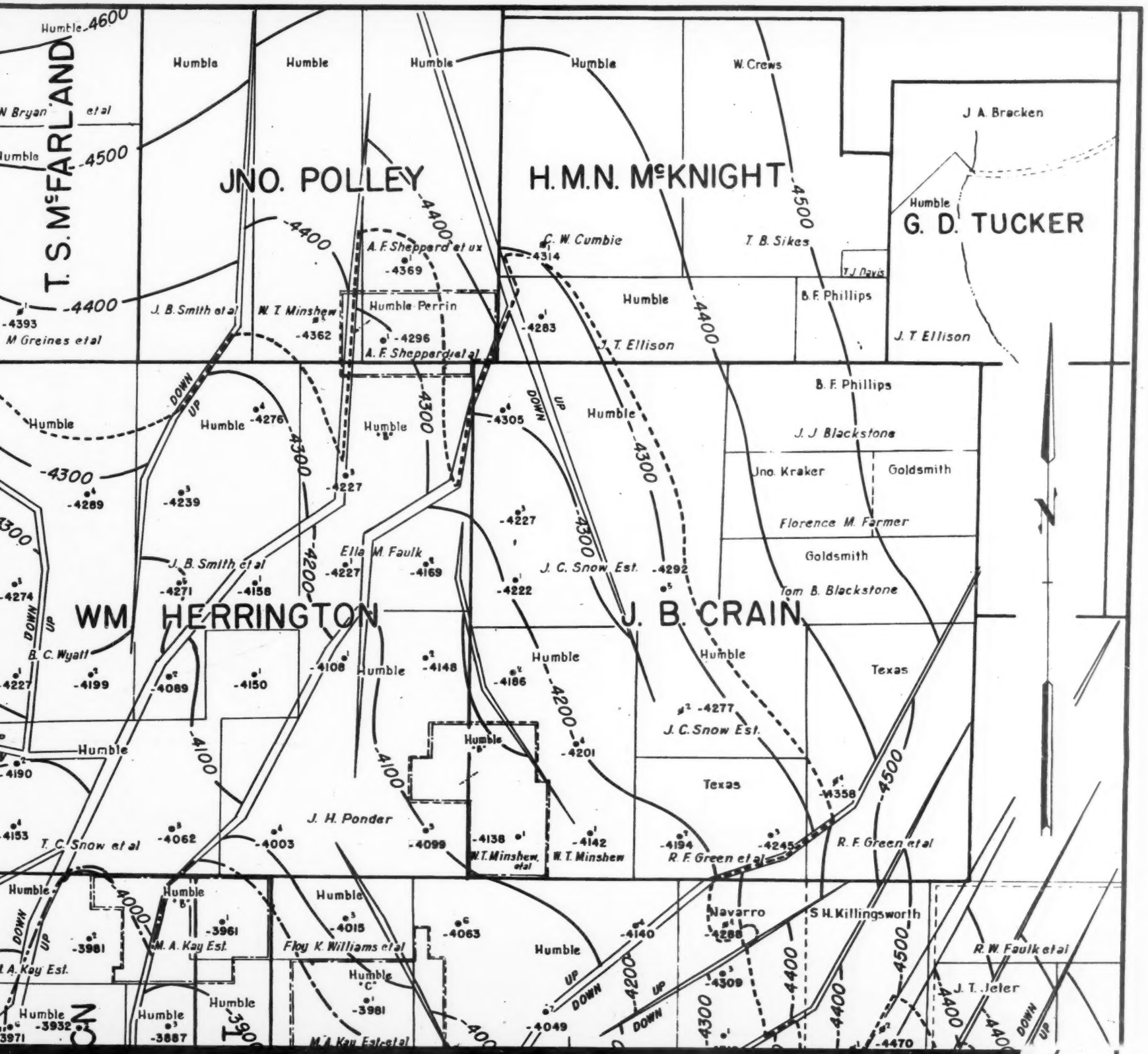
The Paluxy formation encountered was 334 feet thick and contained porous permeable water sands which were devoid of any showings of oil. Since the Woodbine at the crest of the structure is about 735 feet higher than encountered in this well, the Paluxy has not been condemned as a potential producing formation.

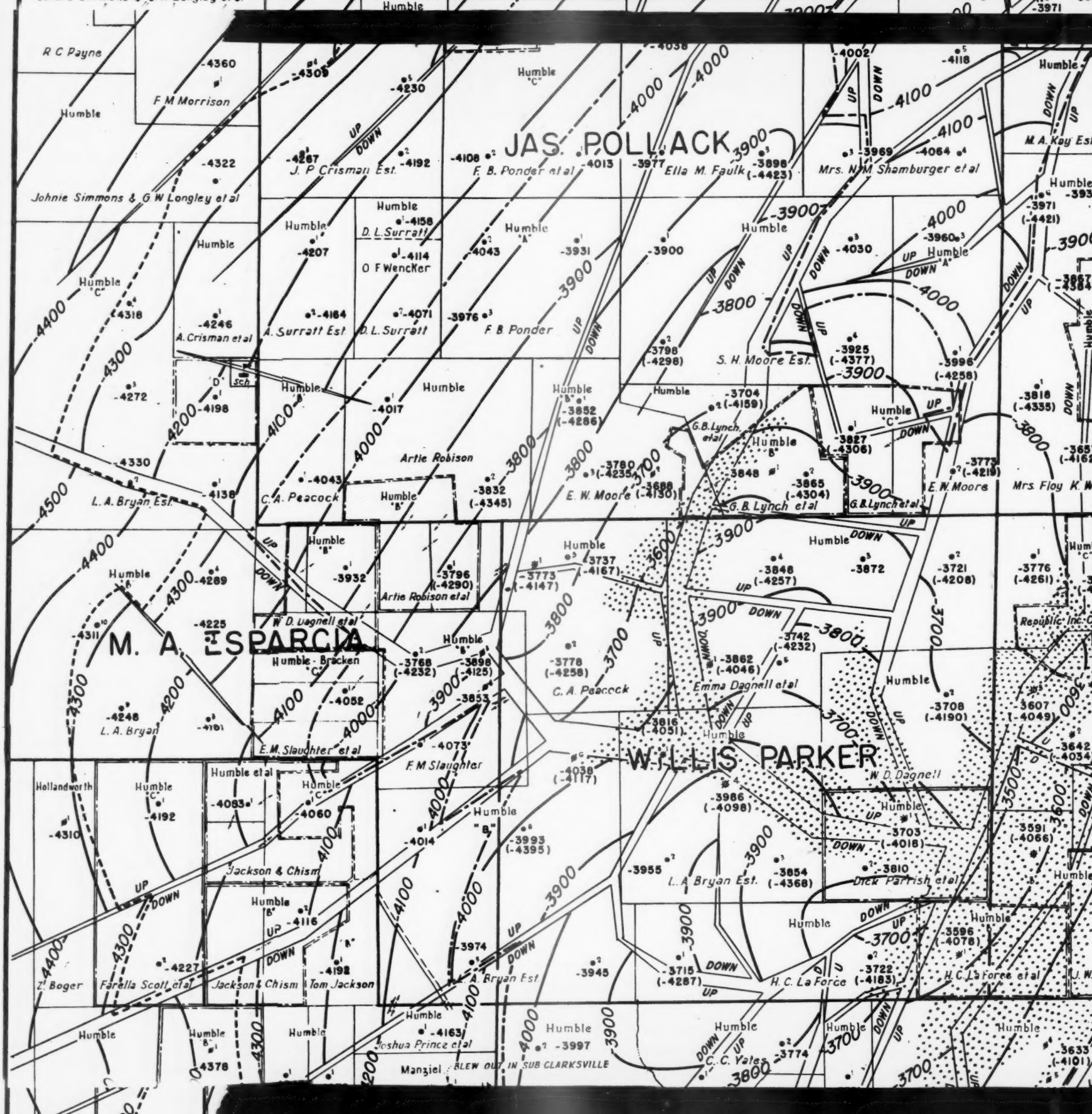


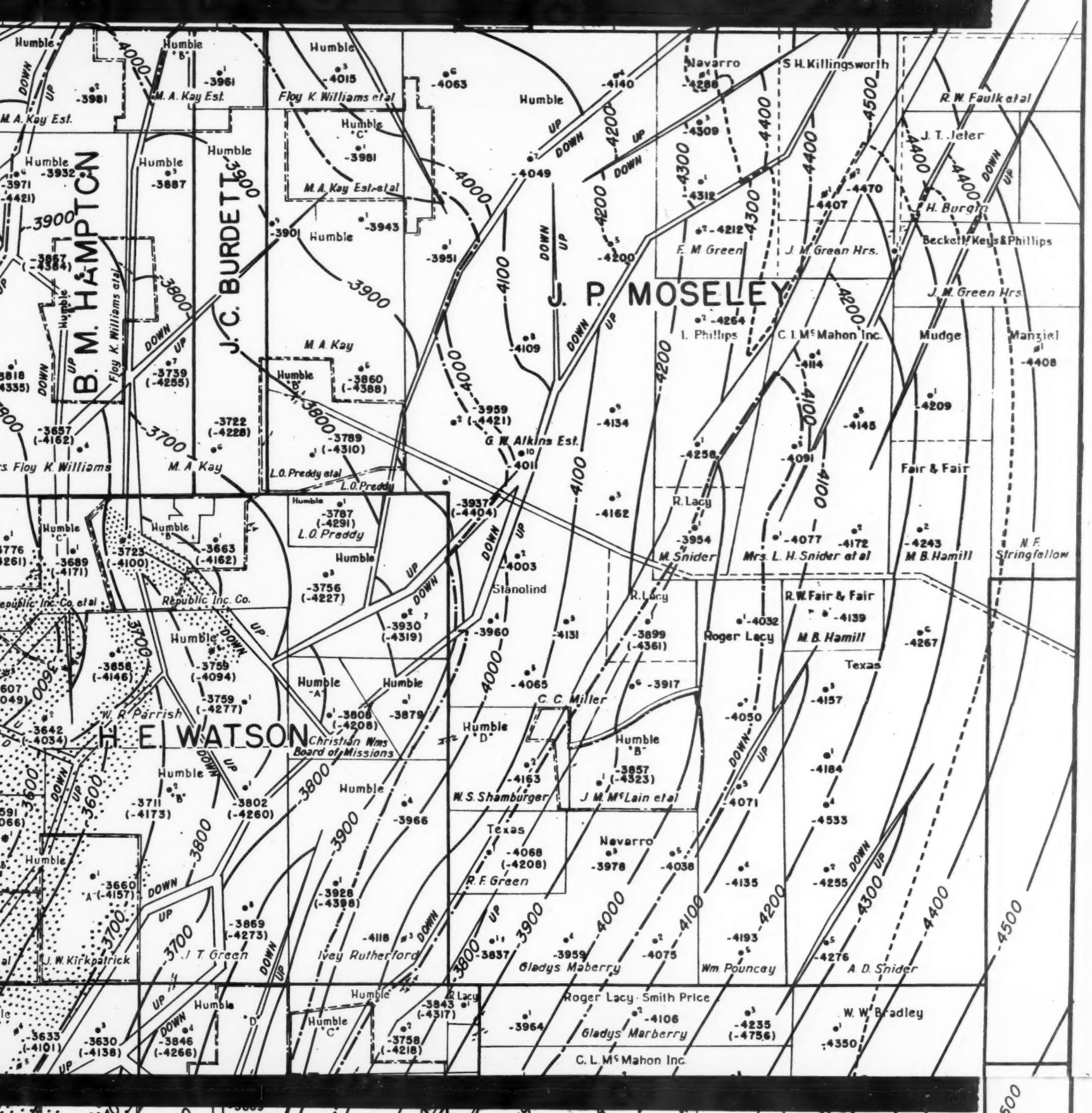
CORE TEST MAP OF HAWKINS AREA
WOOD COUNTY, TEXAS
CONTOURED ON TOP OF CRETACEOUS

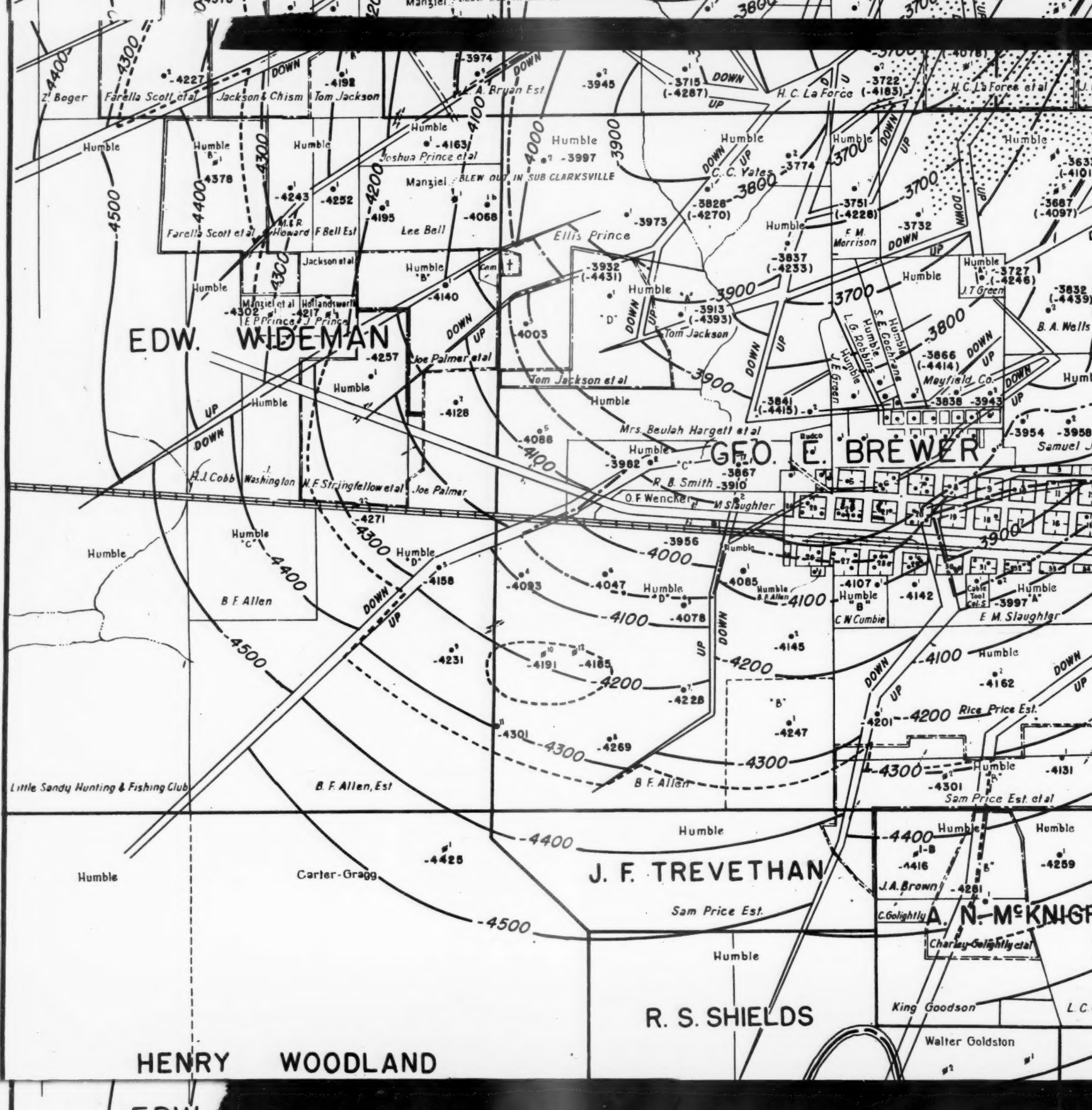
FIG. 3

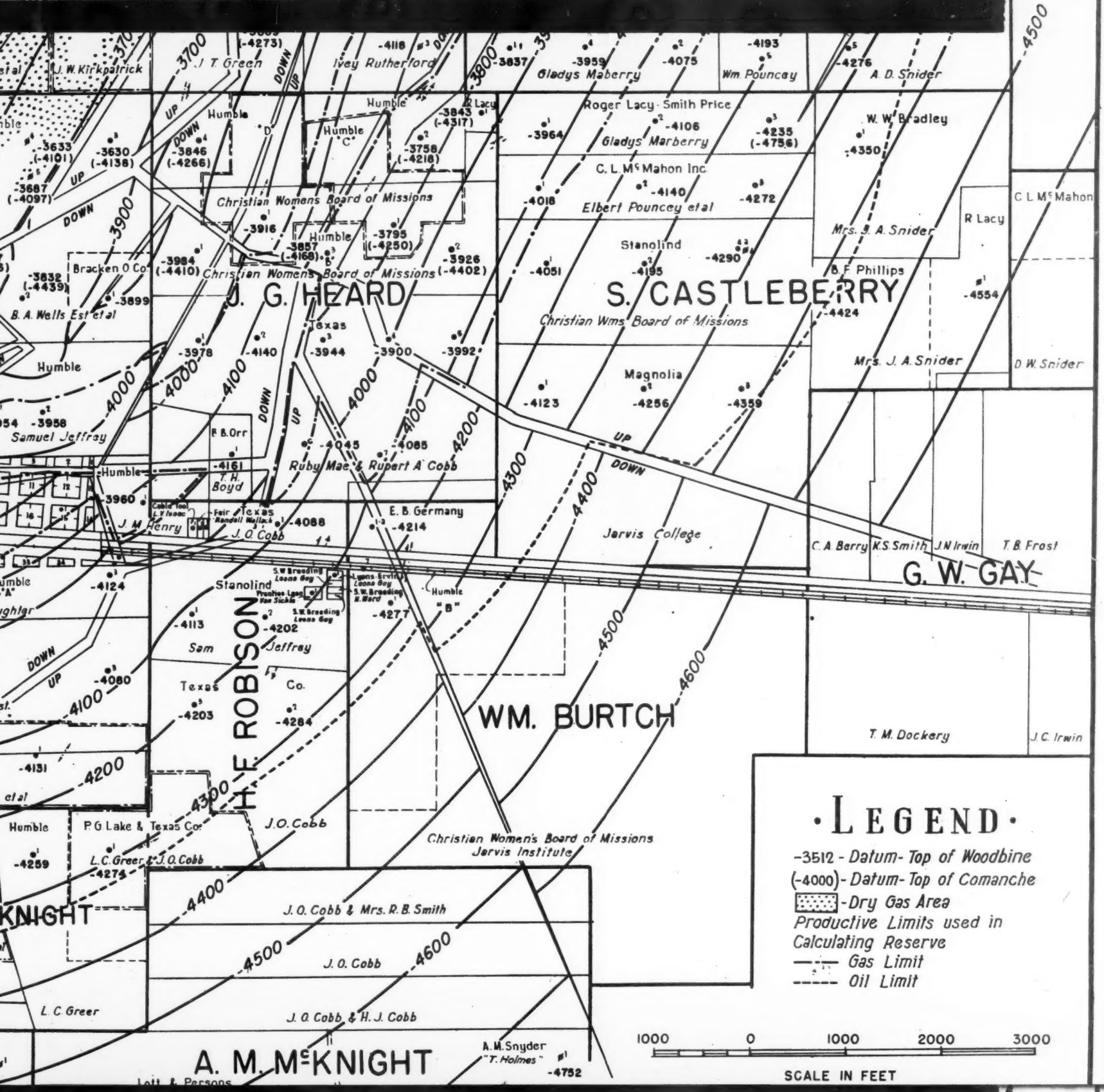

Magnolia
T W. Brittain & C.W Cartwright
Milton, Mackey & Dodson
C. W. Fouke
Humble
HANNAH PAYNE
W. S. Dyke
Magnolia
Cooper & Watts
W. R Wolford
S. E. Allison
Obenchain
B. F. Word, Jr
J. W. Cofer
Humble
R B. Smith
George Willbanks - Dallas Natl. Bk.
Navarro
R W. Willbanks
B. F. Phillips
N. Shamburger
Humble "A"
J M McLain
Humble
A. M. ELLIS
Navarro
D.G. Robinson
E Shamburger
C. F. Eagle
Humble
G R Phillips
JAS. McANULTY
C. H. Shamburger
W. S. Shamburger
W. S. Shamburger
Humble "C"
W. S. Shamburger
W. J. Shamburger Est.
W. J. Shamburger Est.
Mrs. N. M. Shamburger et al
Mrs. N. M. Shamburger et al
T. S. McFARLAND
M. N Bryan
M Greines
B. C. W
M. A. Kay Est
R. W. Fair
Manziel
Humble "B"
W. A. Sample
B. F. Word, Jr.
S. M. Sample, Jr.
Manziel
R C Payne
F. M Morrison
Humble
Johnie Simmons & G W Longley et al
B. Manziel
DISCOVERY WELL
F. T. Morrison
A. T. Cliff
A. T. Cliff et al
Humble
Humble "C"
J. P Crisman Est.
F. B. Ponder et al
JAS. POLLACK
Ella M. Faulk
Humble
-4372
-4312
-4287
-4267
-4310
-4189
-4360
-4309
-4230
-4322
-4267
-4192
-4108
-4013
-3977
-3898
(-4423)
-4064
-3969
-4328
-4385
-4329
-4262
-4277
-4259
-4295
-4231
-4188
-4143
-4171
-4227
-4191
-4109
-4095
-4217
-4038
-3997
-4002
-4118
-4153
-4190
-4274
-4393
-3971
4500
4400
4300
4200
4100
4000
3900
UP
DOWN


T. S. McFARLAND
JNO. POLLEY
H. M. N. McKNIGHT
G. D. TUCKER
WM. HERRINGTON
J. B. CRAIN
Humble
W. Crews
J. A. Bracken
C. W. Cumbie
T. B. Sikes
T. J. Davis
B. F. Phillips
J. T. Ellison
A. F. Sheppard et ux
A. F. Sheppard et al
Humble Perrin
J. B. Smith et al
W. T. Minshew
M. Greines et al
N. Bryan et al
J. J. Blackstone
Jno. Kraker
Goldsmith
Florence M. Farmer
Tom B. Blackstone
Ella M. Faulk
J. C. Snow Est.
B. C. Wyatt
Texas
J. H. Ponder
T. C. Snow et al
R. F. Green et al
W. T. Minshew et al
Navarro
S. H. Killingsworth
R. W. Faulk et al
J. T. Jeter
M. A. Kay Est.
Floy K. Williams et al
M. A. Kay Est. et al
4600
4500
4400
4300
4200
4100
4000
3900
UP
DOWN


JAS. POLLACK
M. A. ESPARZA
WILLIS PARKER
R C Payne
F M Morrison
Johnie Simmons & G W Longley et al
J. P Crisman Est.
F. B. Ponder et al
Ella M. Faulk
Mrs. N M Shamburger et al
D. L. Surratt
O F Wencker
A. Crisman et al
A. Surratt Est.
D. L. Surratt
F. B. Ponder
S. H. Moore Est.
Artie Robison
C. A. Peacock
E. W. Moore
G. B. Lynch et al
L. A. Bryan Est.
W. D. Dagnell et al
Artie Robison et al
Humble - Bracken
L. A. Bryan
E. M. Slaughter et al
F. M. Slaughter
Emma Dagnell et al
W. D. Dagnell
Jackson & Chism
Farella Scott et al
Tom Jackson
A. Bryan Est.
H. C. La Force
Dick Parrish et al
Joshua Prince et al
C. C. Yates
Manziel
BLEW OUT IN SUB CLARKSVILLE
Humble
Hollandsworth


B. M. HAMPTON
J.C. BURDETT
J. P. MOSELEY
H. E. WATSON
Humble
M. A. Kay Est.
Floy K. Williams et al
M. A. Kay Est. et al
M. A. Kay
L. O. Preddy et al
L. O. Preddy
G. W. Alkins Est.
Republic Inc. Co.
Republic Inc. Co. et al
Stanolind
C. C. Miller
W. R. Parrish
Christian Wms Board of Missions
W. S. Shamburger
J. M. McLain et al
R. F. Green
J. T. Green
J. W. Kirkpatrick
Ivey Rutherford
Gladys Maberry
Wm. Pouncey
A. D. Snider
Roger Lacy-Smith Price
C. L. McMahon Inc.
W. W. Bradley
Navarro
S. H. Killingsworth
R. W. Faulk et al
J. T. Jeter
H. Burgin
Beckell, Keys & Phillips
J. M. Green Hrs.
E. M. Green
I. Phillips
C. I. McMahon Inc.
Mudge
Manziel
Fair & Fair
R. W. Fair & Fair
R. Lacy
M. Snider
Mrs. L. H. Snider et al
M. B. Hamill
N. F. Stringfellow
Roger Lacy
Texas
UP
DOWN


EDW. WIDEMAN
GEO. E. BREWER
J. F. TREVETHAN
R. S. SHIELDS
HENRY WOODLAND
A. N. McKNIGHT
Humble
Manziel
Z. Boger
Farella Scott et al
Jackson & Chism
Tom Jackson
A. Bryan Est
H. C. La Force
H. C. La Force et al
Joshua Prince et al
BLEW OUT IN SUB CLARKSVILLE
C. C. Yates
Ellis Prince
E. M. Morrison
J. T. Green
B. A. Wells
Lee Bell
F. Bell Est
M. & R. Howard
Jackson et al
Manziel et al
Hollandsworth
E. P. Prince
J. Prince
Joe Palmer et al
Tom Jackson et al
Mrs. Beulah Hargett et al
L. G. Robbins
S. E. Cochrane
J. E. Green
Mayfield Co.
Samuel J
H. J. Cobb
Washington
W. F. Stringfellow et al
Joe Palmer
R. B. Smith
O. F. Wencker
M. Slaughter
B. F. Allen
C. N. Cumbie
E. M. Slaughter
Rice Price Est.
Sam Price Est. et al
Little Sandy Hunting & Fishing Club
B. F. Allen, Est
Carter-Gragg
Sam Price Est.
J. A. Brown
C. Golightly
Charley Golightly et al
King Goodson
Walter Goldston
DOWN
UP
4500
4400
4300
4200
4100
4000
3900
3800
3700



· LEGEND ·

-3512 - Datum - Top of Woodbine

(-4000) - Datum - Top of Comanche

Dry Gas Area

Productive Limits used in Calculating Reserve

Gas Limit

Oil Limit

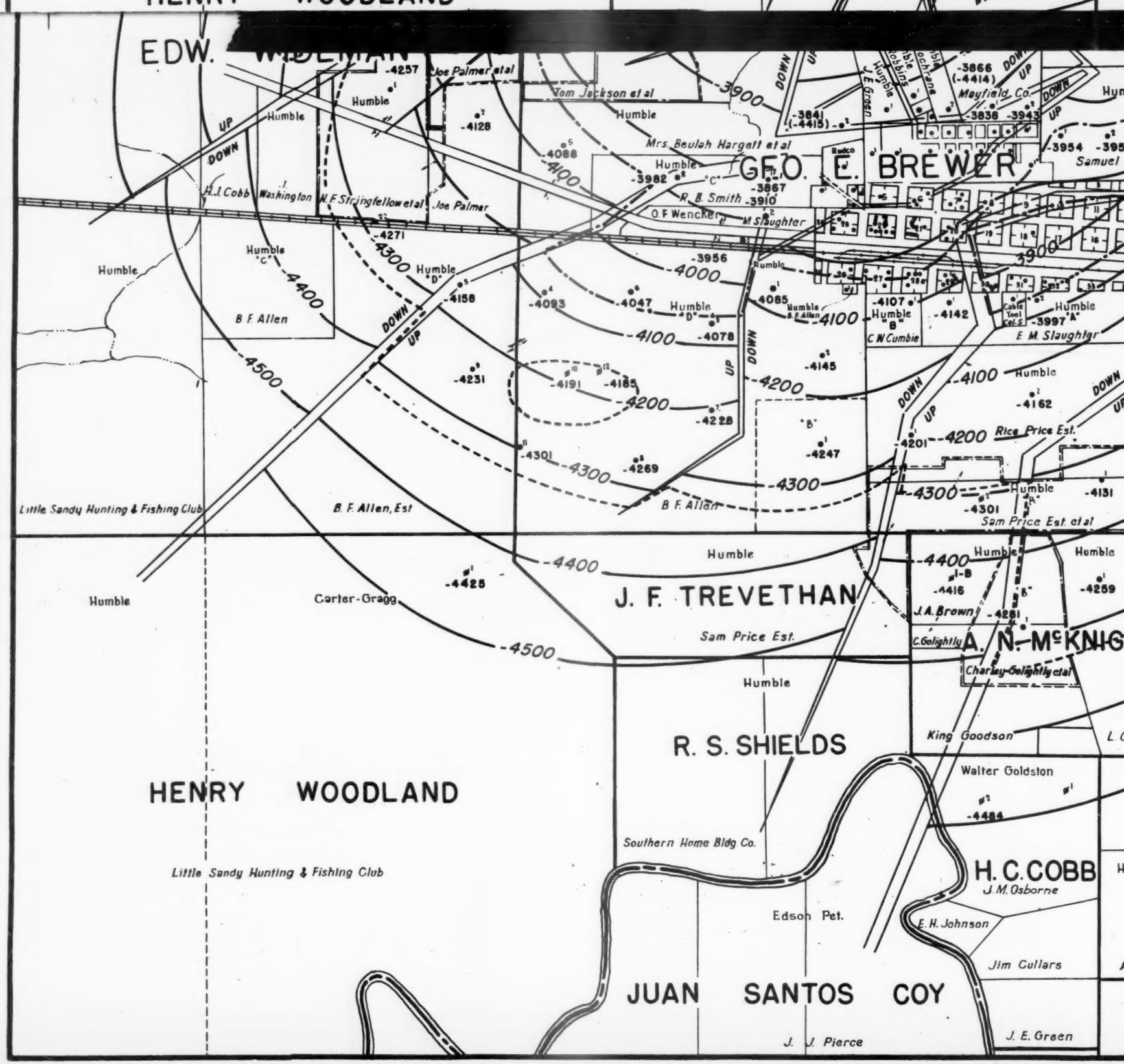

EDW. WIDEMAN
GEO. E. BREWER
J. F. TREVETHAN
R. S. SHIELDS
HENRY WOODLAND
JUAN SANTOS COY
H. C. COBB
A. N. McKNIG
B. F. Allen
B. F. Allen, Est
Little Sandy Hunting & Fishing Club
Carter-Gragg
Sam Price Est.
Rice Price Est.
Sam Price Est. et al
Southern Home Bldg Co.
Edson Pet.
J. J. Pierce
J. E. Green
E. H. Johnson
Jim Cullars
J. M. Osborne
King Goodson
Walter Goldston
J. A. Brown
Charley Golightly et al
C. Golightly
Mayfield Co.
Tom Jackson et al
Joe Palmer et al
Joe Palmer
W. F. Stringfellow et al
H. J. Cobb
Washington
R. B. Smith
O. F. Wencker
M. Slaughter
Mrs. Beulah Hargett et al
C. N. Cumbie
E. M. Slaughter
Humble
UP
DOWN
3900
4000
4100
4200
4300
4400
4500

FIG. 4

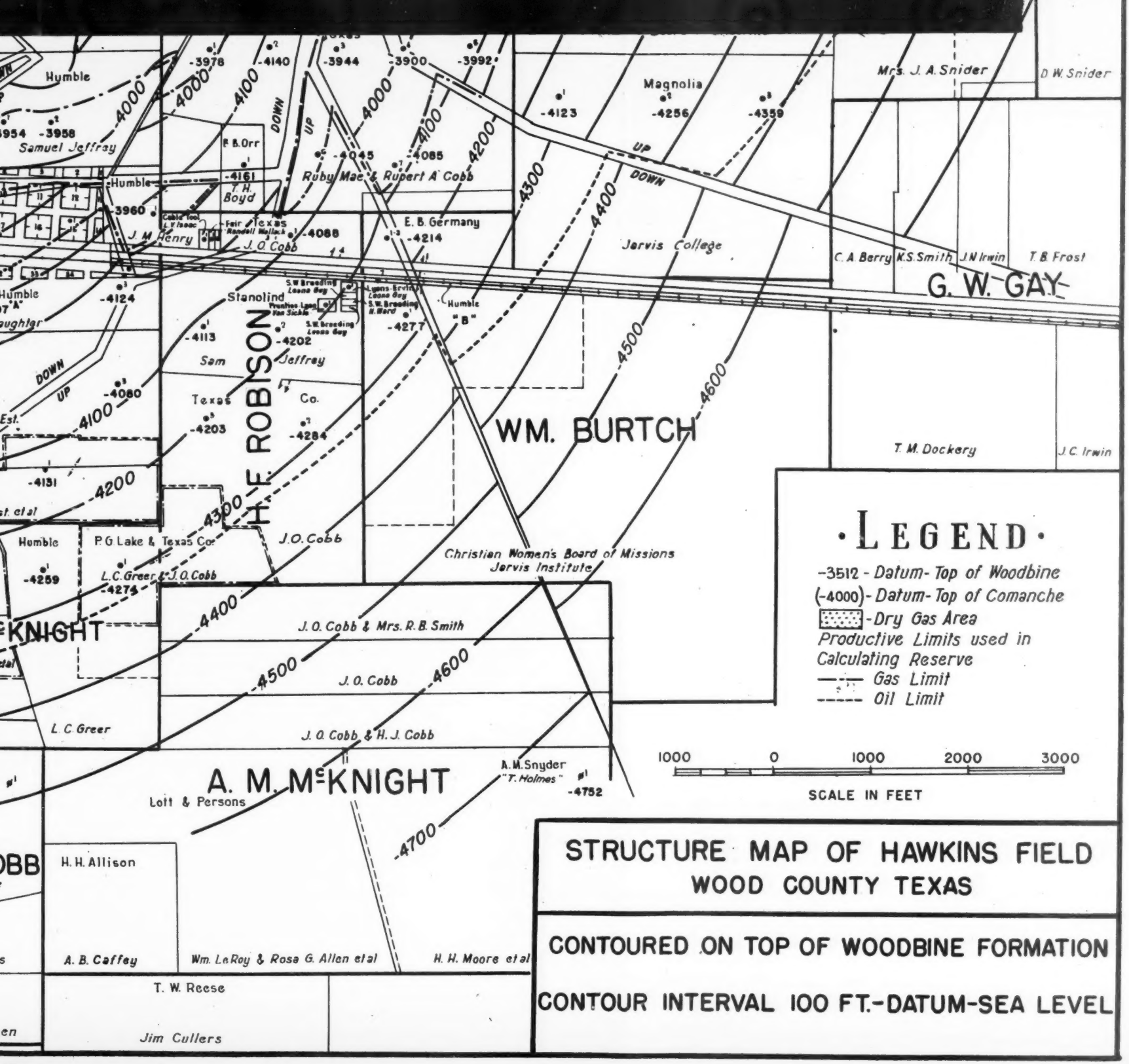
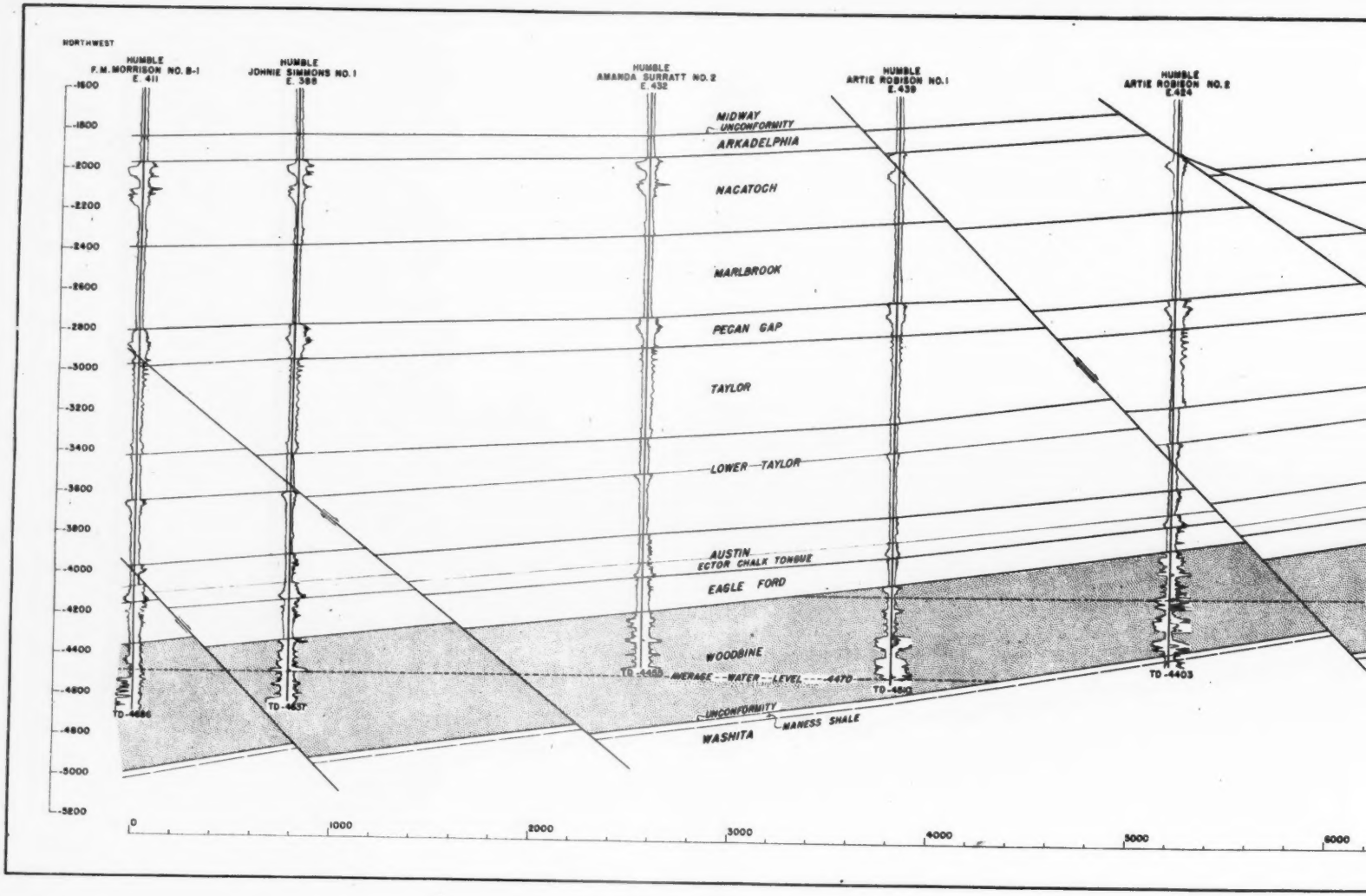

Humble
-3978
-4140
-3944
-3900
-3992
Mrs. J. A. Snider
D W. Snider
Magnolia
-4123
-4256
-4359
Samuel Jeffray
P. B. Orr
-4161
T. H. Boyd
-4045
-4085
Ruby Mae & Rupert A Cobb
Humble
-3960
J. M. Henry
J. O. Cobb
E. B. Germany
-4214
-4088
Jarvis College
C. A. Berry
K.S. Smith
J.N Irwin
T. B. Frost
G. W. GAY
Humble
-4124
Stanolind
Humble "B"
-4277
-4113
-4202
Sam Jeffray
H. F. ROBISON
Texas Co.
-4203
-4284
WM. BURTCH
T. M. Dockery
J.C. Irwin
-4131
Humble
-4259
P G Lake & Texas Co.
L.C. Greer & J.O. Cobb
-4275
J.O. Cobb
Christian Women's Board of Missions
Jarvis Institute
KNIGHT
J. O. Cobb & Mrs. R. B. Smith
J. O. Cobb
L. C Greer
J. O. Cobb & H. J. Cobb
A. M. McKNIGHT
Loft & Persons
A. M. Snyder
"T. Holmes"
-4752
H. H. Allison
A. B. Caffey
Wm. LeRoy & Rosa G. Allen et al
H. H. Moore et al
T. W. Reese
Jim Cullers
4000
4100
4200
4300
4400
4500
4600
4700
UP
DOWN
·LEGEND·
-3512 - Datum- Top of Woodbine
(-4000) - Datum- Top of Comanche
Dry Gas Area
Productive Limits used in Calculating Reserve
Gas Limit
Oil Limit
1000 0 1000 2000 3000
SCALE IN FEET
STRUCTURE MAP OF HAWKINS FIELD
WOOD COUNTY TEXAS
CONTOURED ON TOP OF WOODBINE FORMATION
CONTOUR INTERVAL 100 FT.-DATUM-SEA LEVEL

FIG. 4


NORTHWEST
HUMBLE F.M. MORRISON NO. B-1 E. 411
HUMBLE JOHNIE SIMMONS NO. 1 E. 388
HUMBLE AMANDA BURRATT NO. 2 E. 432
HUMBLE ARTIE ROBISON NO. 1 E. 439
HUMBLE ARTIE ROBISON NO. 2 E. 424
MIDWAY
UNCONFORMITY
ARKADELPHIA
NACATOCH
MARLBROOK
PECAN GAP
TAYLOR
LOWER TAYLOR
AUSTIN
ECTOR CHALK TONGUE
EAGLE FORD
WOODBINE
AVERAGE WATER LEVEL 470
TD -4686
TD -4637
TD -4465
TD -4503
TD -4403
UNCONFORMITY
WASHITA
MANESS SHALE
-1600
-1800
-2000
-2200
-2400
-2600
-2800
-3000
-3200
-3400
-3600
-3800
-4000
-4200
-4400
-4600
-4800
-5000
-5200
0
1000
2000
3000
4000
5000
6000

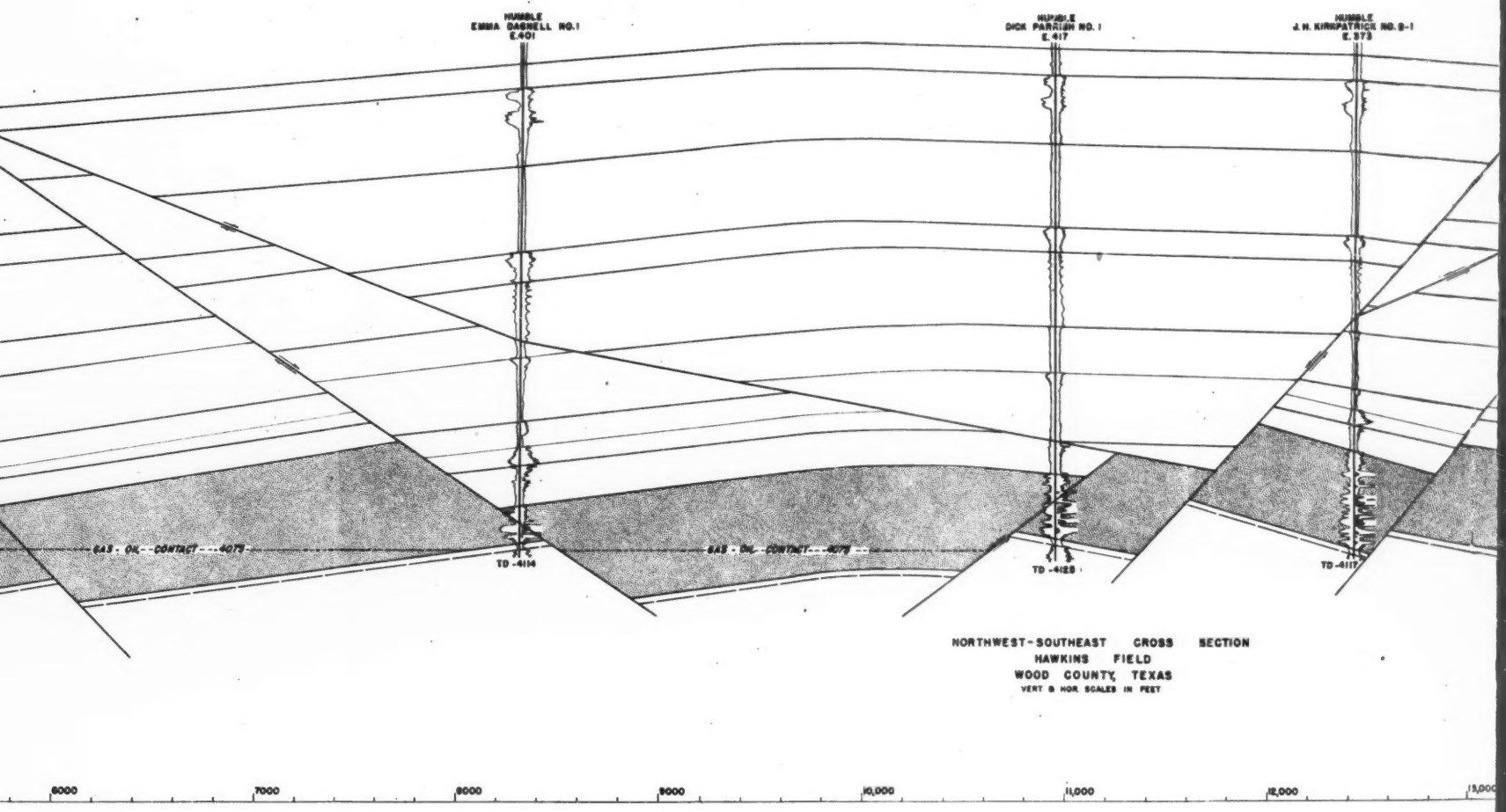
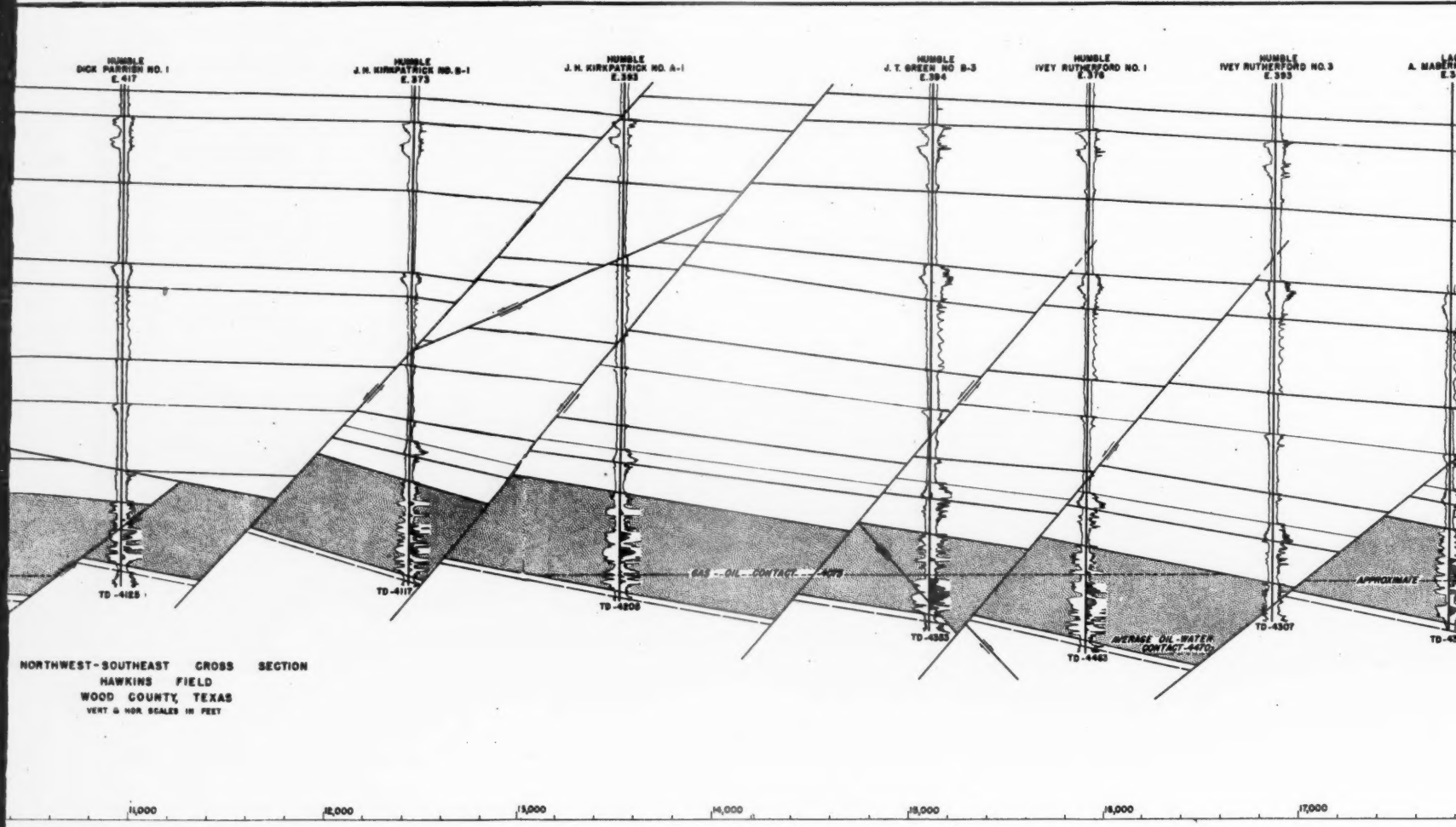
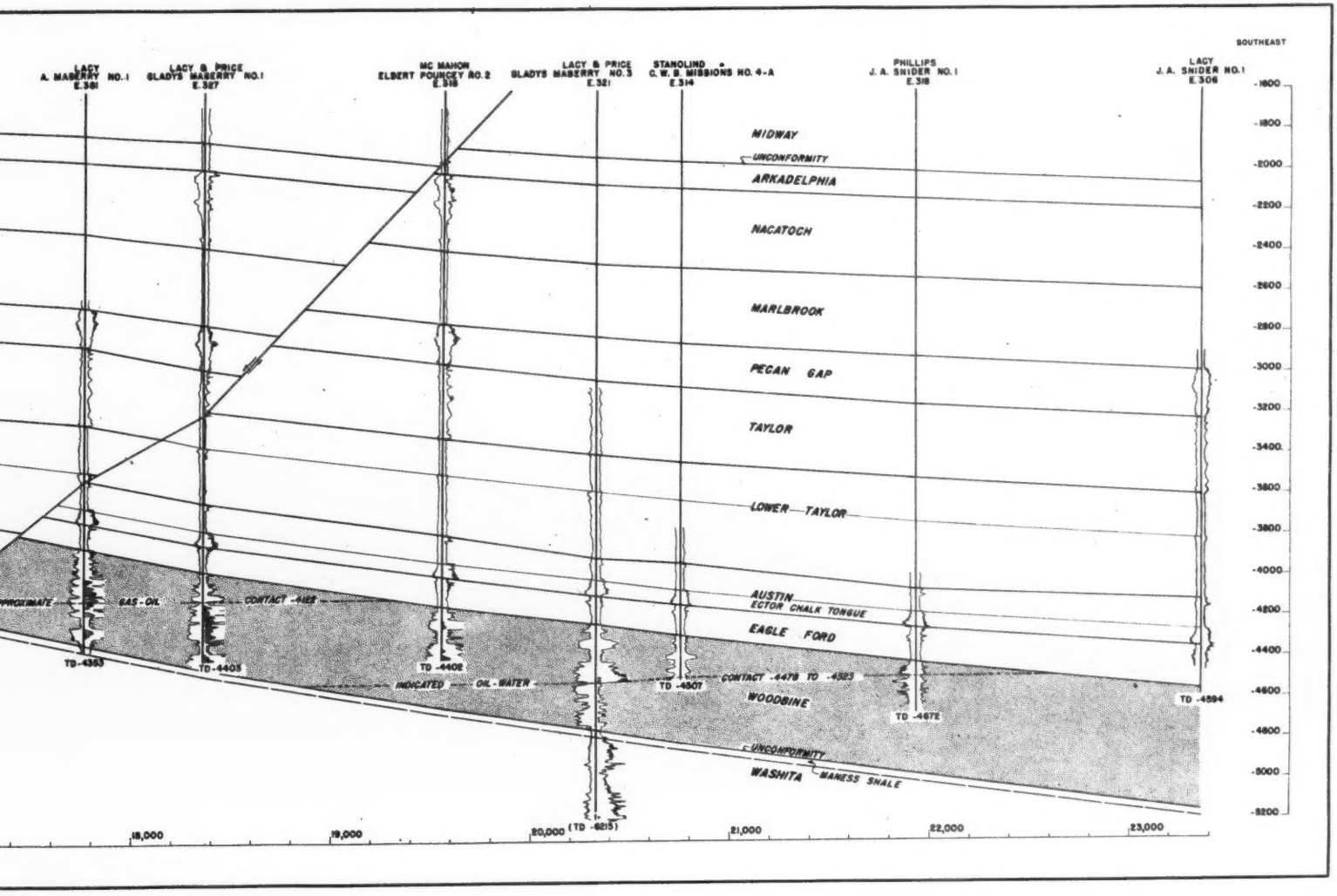

HUMBLE
EMMA DASWELL NO. 1
E.401
HUMBLE
DICK PARRISH NO. 1
E.417
HUMBLE
J. H. KIRKPATRICK NO. 2-1
E. 373
GAS - OIL CONTACT -4075'
GAS - OIL CONTACT -4078'
TD -4114
TD -4125
TD -4117
NORTHWEST-SOUTHEAST CROSS SECTION
HAWKINS FIELD
WOOD COUNTY, TEXAS
VERT. & HOR. SCALES IN FEET
6000
7000
8000
9000
10,000
11,000
12,000

FIG. 5



NORTHWEST - SOUTHEAST CROSS SECTION
HAWKINS FIELD
WOOD COUNTY, TEXAS
VERT & HOR SCALES IN FEET

FIG. 5


SOUTHEAST
LACY
A. MABERRY NO. 1
E.301
LACY & PRICE
GLADYS MABERRY NO. 1
E.307
MC MAHON
ELBERT POWELL NO. 2
E.315
LACY & PRICE
GLADYS MABERRY NO. 3
E.321
STANOLIND
C. W. B. MISSIONS NO. 4-A
E.314
PHILLIPS
J. A. SNIDER NO. 1
E.318
LACY
J. A. SNIDER NO. 1
E.306
MIDWAY
UNCONFORMITY
ARKADELPHIA
NACATOCH
MARLBROOK
PECAN GAP
TAYLOR
LOWER TAYLOR
AUSTIN
ECTOR CHALK TONGUE
EAGLE FORD
WOODBINE
UNCONFORMITY
WASHITA
MANESS SHALE
GAS - OIL
CONTACT -4152
INDICATED OIL - WATER
CONTACT -4478 TO -4523
TD -4383
TD -4405
TD -4402
TD -4507
TD -4672
TD -4594
(TD -6215)
-1600
-1800
-2000
-2200
-2400
-2600
-2800
-3000
-3200
-3400
-3600
-3800
-4000
-4200
-4400
-4600
-4800
-5000
-5200
18,000
19,000
20,000
21,000
22,000
23,000

However, any possibilities from this horizon would be restricted to a smaller producing area than the Woodbine. The unique character of the Woodbine oil in this field leads to the speculation that it might contain an admixture of Paluxy oil which has migrated up the faults. Assuming this is true, no large accumulation would be expected in the Paluxy.

The prospects for production below the Paluxy are largely speculative. However, any porous strata present in the Glen Rose and Travis Peak sections of Comanche age or the Cotton Valley and Smackover sections of Jurassic age offer some chance for deeper production.

RELATION OF ACCUMULATION TO STRUCTURE

Woodbine.—A total oil and gas column of more than 1,000 feet has accumulated in the Woodbine sands on this anticline. On the crest of the structure the top of the Woodbine formation occurs at about 3,500 feet subsea. At present there are 8,372 oil-producing acres in the field, which is approximately 5 miles long and 4 miles wide. In the central part of the uplift there is an area of about 400 acres under which Washita sediments occur above the gas-oil contact. As a result, this area is barren of oil since the entire Woodbine formation is in the gas column. The gas cap overlying the oil in the Woodbine formation covers approximately 3,600 acres. It is estimated that the total productive area of the field will probably exceed 9,500 acres.

None of the faults represented on the Woodbine structure map (Fig. 4) is of sufficient magnitude to prevent free intercommunication of the Woodbine sands except the large northeast-trending fault through the J. G. Heard and J. P. Mosley surveys on the east flank of the structure. The maximum displacement of this fault is about 375 feet, the largest of any in the field. Although some restricted communication may exist along the fault, particularly near the south end where a smaller radial fault in the J. G. Heard and Samuel Burch surveys and local poor sand conditions combine to complete the barrier, this fault divides the field into two areas with separate reservoir characteristics. The area east of the fault and north of the radial fault has been designated East Hawkins and contains about 15 per cent of the producnig area of the field. The remaining 85 per cent lying west of this fault segment has been designated West Hawkins.

Sub-Clarksville.—The thin sub-Clarksville sands which occur in the upper part of the Eagle Ford formation on the Hawkins structure are locally absent on the higher parts of the uplift. Where porous sub-Clarksville sands are present, they contain gas even below the Woodbine gas-oil contact. Since it appears probable that faulting has brought these sands locally in juxtaposition with Woodbine oil sand, the fact that they contain only gas may be due to poor permeability and thin erratic sand development. Several pressure tests appear to substantiate the presence of poor communication. The area proved for gas production, which extends beyond the Woodbine oil productive limits, is estimated to contain about 4,700 acres.

RESERVOIR CHARACTERISTICS

In the development of the Hawkins field and in subsequent production, there has probably been more subsurface information accumulated than on any other field developed in the East Texas district. Electric logs have been run on each well, and approximately 13,800 feet of Woodbine formation in 77 Humble Oil and Refining Company wells has been cored with an average of 80 per cent recovery. A study of bottom-hole pressures was begun shortly after the discovery of the field, and thorough pressure surveys have been made at frequent intervals, especially in West Hawkins.

Figure 6 is an isopach map of the Hawkins field showing the effective Woodbine oil sand thickness by isopach contours drawn at 50-foot intervals. The average effective oil sand thickness of the entire field is about 107 feet. Figure 7 is an isopach map showing the effective Woodbine gas sand thickness by isopach contours at intervals of 50 feet. The average gas sand thickness of the entire field is 83 feet.

Sands in the Lewisville member of the Woodbine formation have an average porosity of 24.6 per cent and an average permeability of approximately 450 millidarcys. Although the sands in this member are in communication with the Dexter sands in general as evidenced by common fluid contacts, the communication between these sands is poor, due to the lenticular nature and low permeability of the Lewisville sands. This is demonstrated by the rapid decline of bottom-hole pressure in many of the edge wells completed in the Lewisville. There are a few instances where local sand lenses in the Lewisville have independent fluid contacts.

The Dexter member of the Woodbine is essentially a sheet sand with intercalated lenses of shale. The average porosity of the sands in this member is 27.4 per cent, and their average permeability is approximately 3,000 millidarcys. The maximum permeability observed in Dexter sands is 21,700 millidarcys. The pressure communication of the Dexter sands is excellent throughout both the West Hawkins and the East Hawkins reservoirs. For purposes of estimating the original oil in place, it is estimated that the connate water in the Dexter sands occupies 30 per cent of the pore volume, with a somewhat higher percentage indicated in the Lewisville sands.

Gravitational segregation within the oil sands at Hawkins is evident with the oil becoming heavier and more asphaltic as lower subsea depths are reached, both within individual sand bodies and in the over-all reservoir. This has resulted in a band of extremely heavy, non-producible asphalt being deposited at the oil-water contact in thicknesses varying from 3 to 10 feet or more which is too viscous to flow under reservoir conditions in West Hawkins. This asphalt layer is found in both the Lewisville and Dexter sands but is generally thicker in the Dexter sands.

It is believed that both East Hawkins and West Hawkins had common fluid contacts up until a few years prior to the field discovery, the gas-oil contact oc-

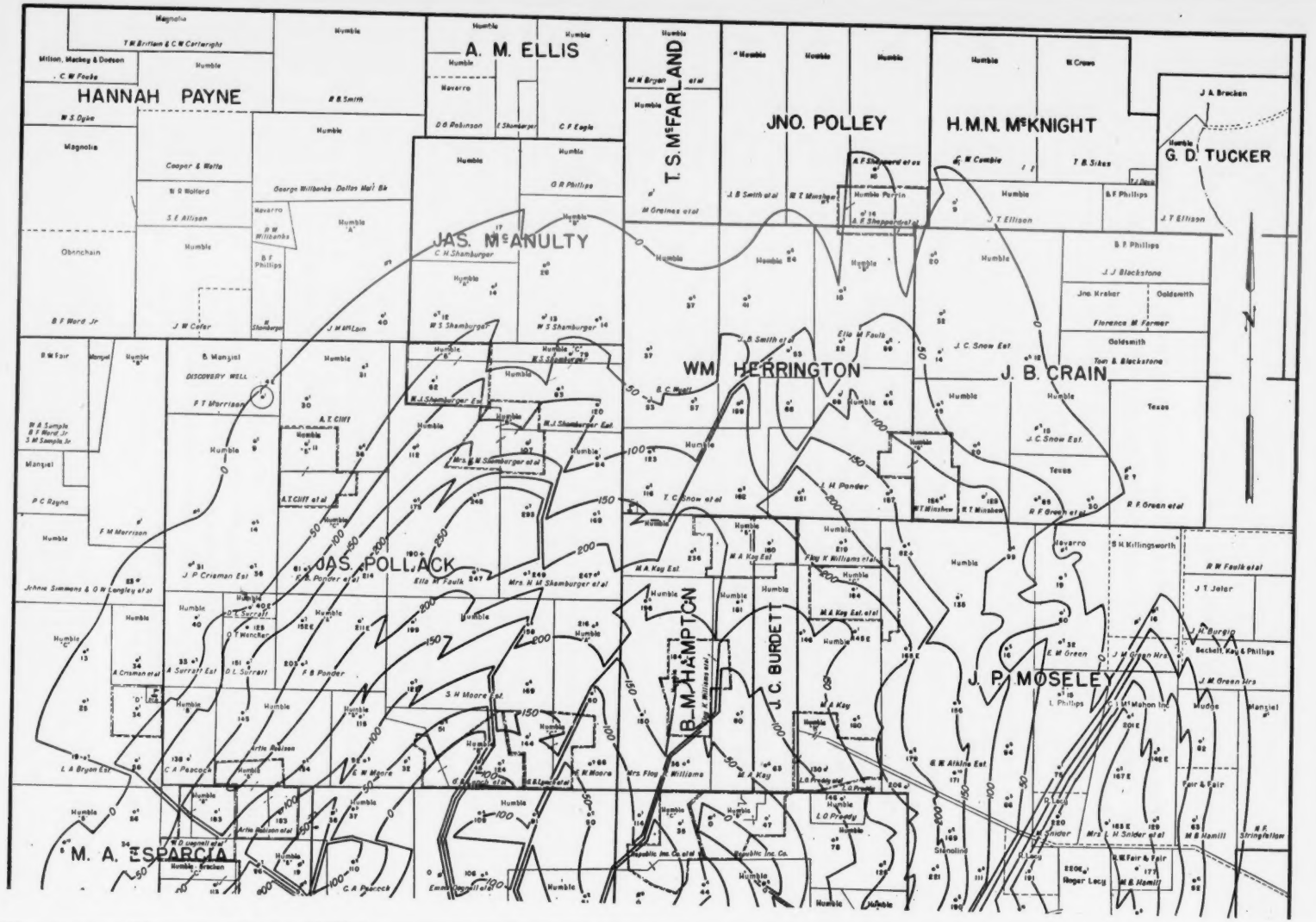
curring at 4,075 feet subsea and the oil-water contact at about 4,470 feet subsea. This thought is supported by the occurrence of oil staining in gas sands below 4,075 feet subsea in East Hawkins and by the erratic oil-water contact which occurs below 4,470 feet subsea in the less permeable sands and ranges downward as low as 4,541 feet subsea in the highly permeable Dexter sands.

An unpublished study of the pressure behavior in the Dexter sands of the entire Woodbine basin indicates definitely that the pressure in the water surrounding the Hawkins field at the time of discovery had decreased to a value of 1,710 pounds, corrected to 4,075 feet subsea by using an oil gradient from the oil-water to the gas-oil contact. This decrease in pressure is attributed mainly to the large fluid withdrawals in the East Texas field, although fluid withdrawals at Van and other fields no doubt contributed to some extent. The asphalt seal at the oil-water contact in West Hawkins was sufficient to contain the original bottom-hole pressure of 1,990 pounds. In East Hawkins the seal ruptured, thereby allowing the gas cap in this isolated block to expand, and the oil was forced downward until equilibrium was reached at 1,710 pounds.

Core analyses, visual observation of cores, and production tests have established that the gas-oil contact in East Hawkins is somewhat variable and occurs between 4,122 and 4,135 feet subsea. The oil-water contact has been found to occur between 4,479 and 4,541 feet subsea. There is an average of 116 feet of effective oil sand in East Hawkins, and the maximum thickness penetrated to date is 236 feet.

In West Hawkins, the original gas-oil contact occurred at 4,075 feet subsea. with the exception of local lenticular Lewisville sand on the northwest flank, the water level occurs at about 4,470 feet subsea. Two wells on the northwest flank produce from 4,503 to 4,508 feet and from 4,533 to 4,541 feet subsea, respectively. A lenticular water sand in the Lewisville occurs above the oil in a limited area on the south flank of the structure. The average effective oil sand thickness in West Hawkins is about 106 feet. The maximum thickness penetrated to date is 293 feet.

A very complete pressure history of the Hawkins field has been maintained, and through the life of the field a definite trend in pressure performance has been established. This information, supplementing other data, definitely established the fact that separate reservoirs are now present in the East Hawkins and West Hawkins areas. An isobaric map as of September 1, 1945 (Fig. 8), shows a low-pressure belt around the periphery of the field. Most of the wells in this area are completed in the Lewisville sand, which had an average pressure of 1,665 pounds in that part of the sand currently producing. Many extremely low-pressure wells are noted, reflecting poor permeability and sand communication. In comparison, the average pressure in the Dexter sand of West Hawkins was 1,816 pounds. The excellent communication in this zone is indicated by the slight pressure differentials between wells except in the south part of the field, where heavy withdrawals from the townsite have resulted in a low-pressure area. In East Hawkins the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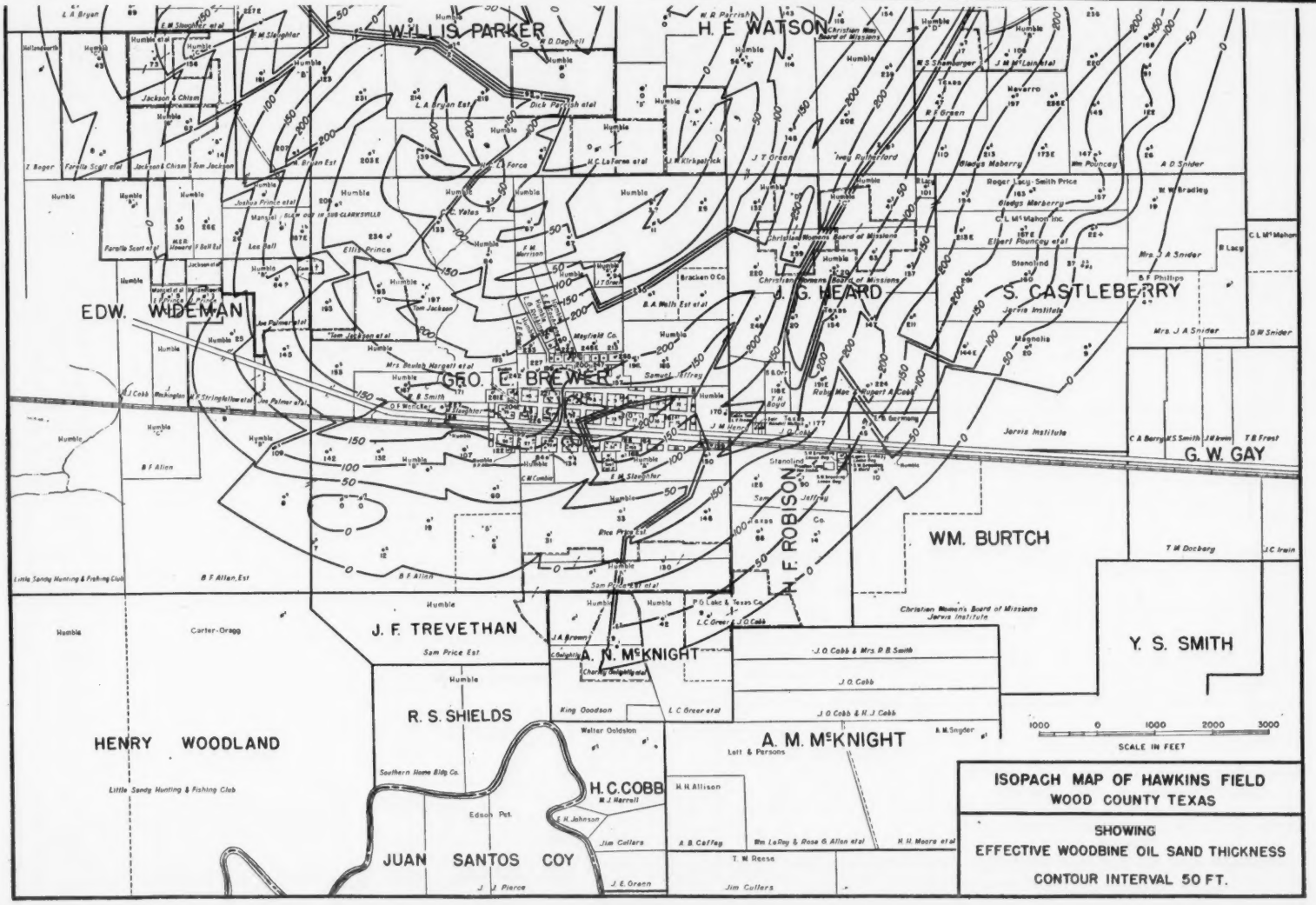
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R. S. SHIELDS
HENRY WOODLAND
A. M. McKNIGHT
H. C. COBB
JUAN SANTOS COY
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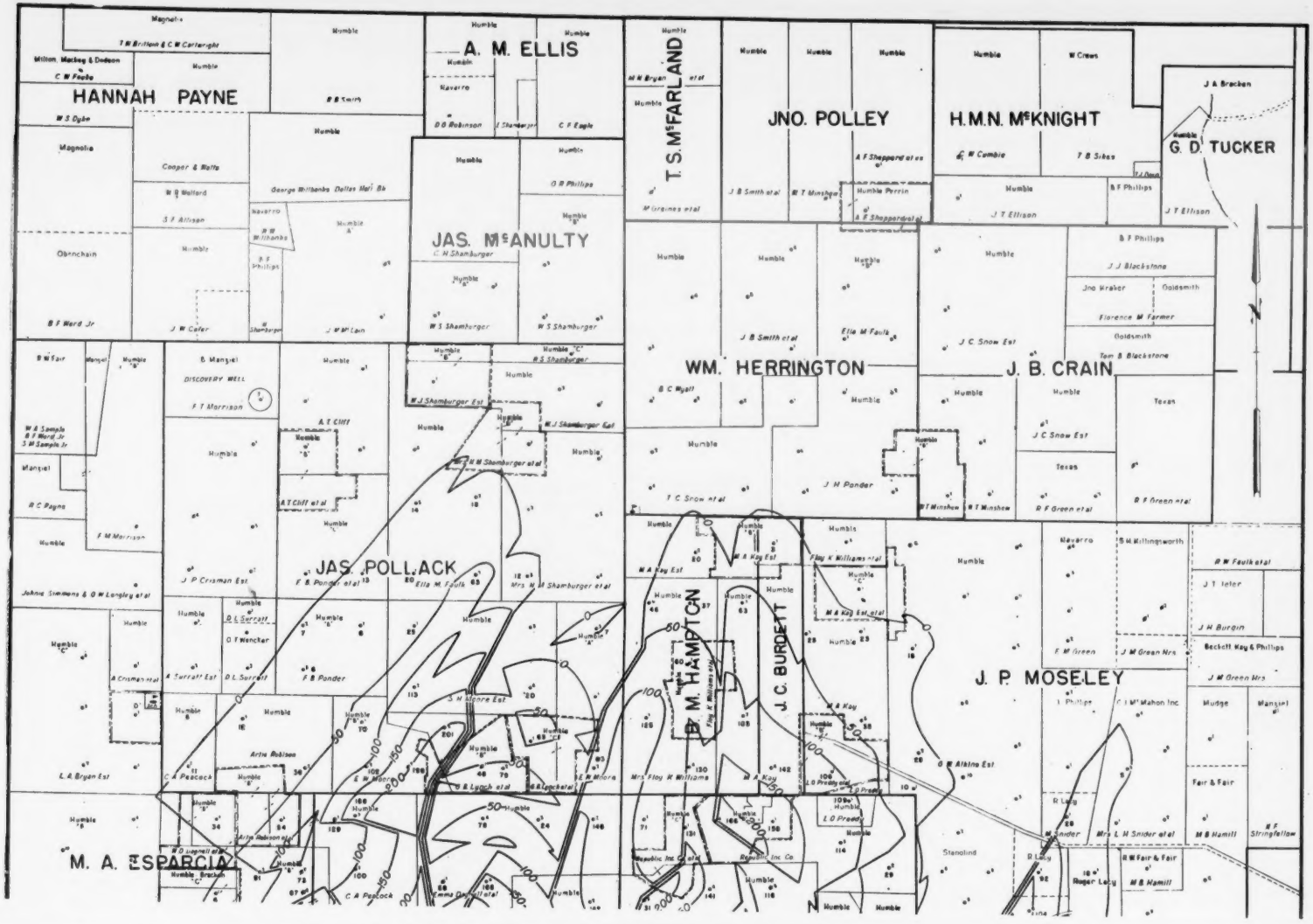
Jarvis Institute
Christian Women's Board of Missions
Little Sandy Hunting & Fishing Club
Southern Home Bldg. Co.
1000 0 1000 2000 3000
SCALE IN FEET
ISOPACH MAP OF HAWKINS FIELD
WOOD COUNTY TEXAS
SHOWING
EFFECTIVE WOODBINE OIL SAND THICKNESS
CONTOUR INTERVAL 50 FT.

FIG. 6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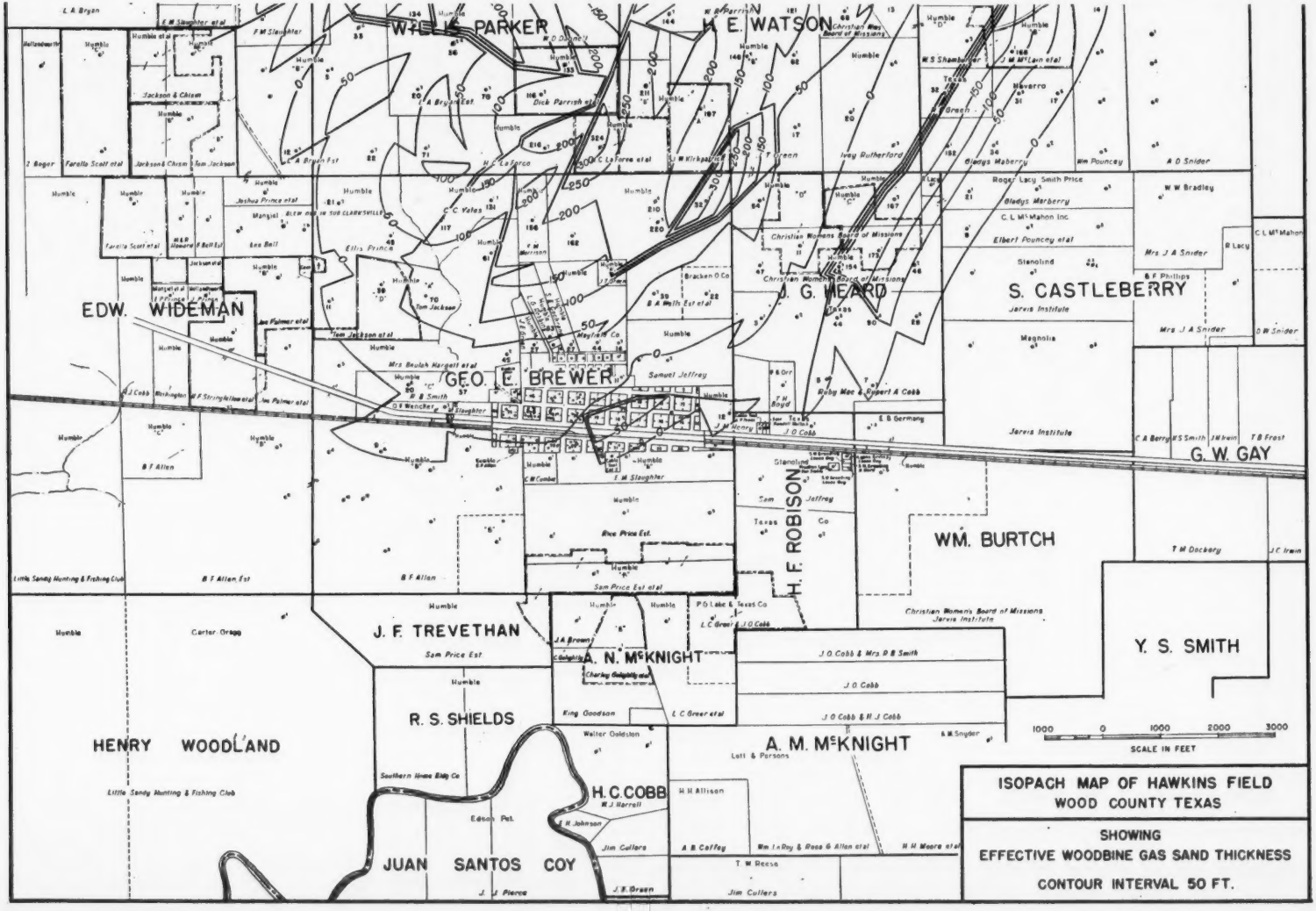
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GEO. E. BREWER
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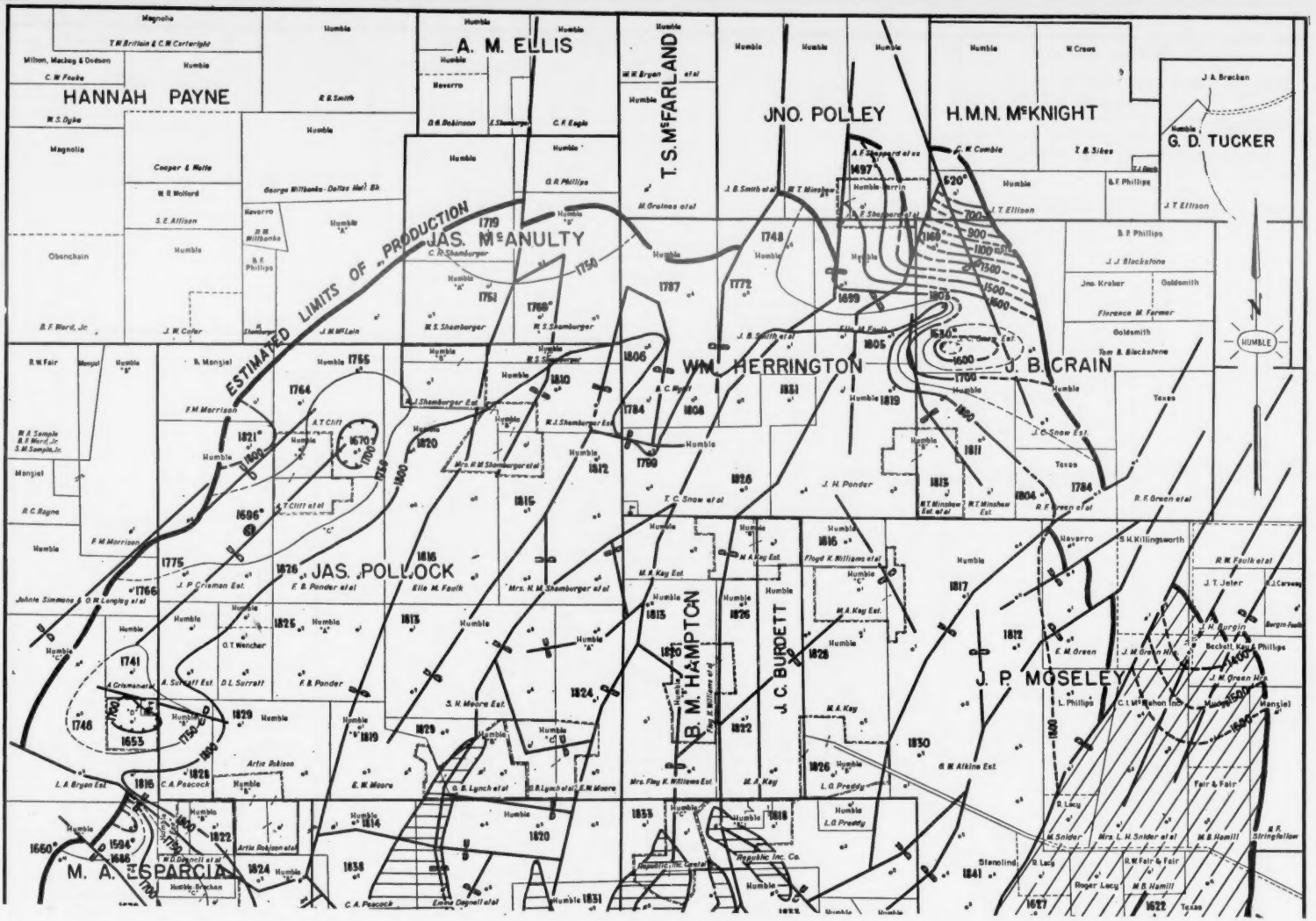
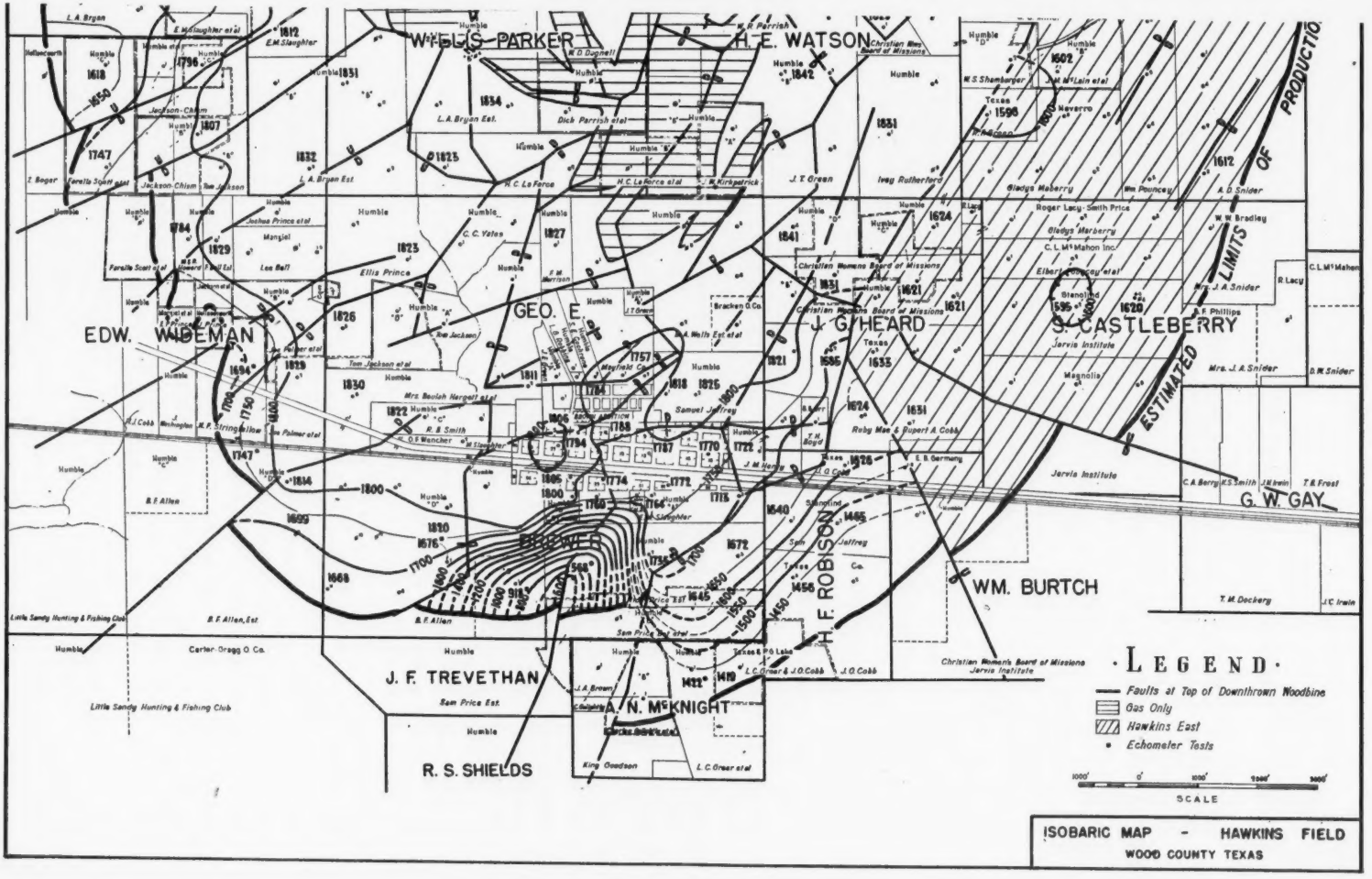
H. C. COBB
JUAN SANTOS COY
Humble
Jarvis Institute
Christian Women's Board of Missions
Sam Price Est
Little Sandy Hunting & Fishing Club
1000 0 1000 2000 3000
SCALE IN FEET
ISOPACH MAP OF HAWKINS FIELD
WOOD COUNTY TEXAS
SHOWING
EFFECTIVE WOODBINE GAS SAND THICKNESS
CONTOUR INTERVAL 50 FT.


A. M. ELLIS
HANNAH PAYNE
T. S. McFARLAND
JNO. POLLEY
H.M.N. McKNIGHT
G. D. TUCKER
ESTIMATED LIMITS OF PRODUCTION
JAS. McANULTY
WM. HERRINGTON
J. B. CRAIN
JAS. POLLOCK
B. M. HAMPTON
J. C. BURDETT
J. P. MOSELEY
M. A. ESPARZA
HUMBLE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GEO. E
J. G. HEARD
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BRUNER
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WM. BURTCH
G. W. GAY
J. F. TREVETHAN
A. N. McKNIGHT
R. S. SHIELDS
ESTIMATED LIMITS OF PRODUCTIO
Jarvis Institute
Christian Womens Board of Missions
Sam Price Est.
Little Sandy Hunting & Fishing Club
Carter-Bragg O. Co.
LEGEND
Faults at Top of Downthrown Woodbine
Gas Only
Hawkins East
Echometer Tests
SCALE
ISOBARIC MAP - HAWKINS FIELD
WOOD COUNTY TEXAS

FIG. 8

pressure had declined to 1,608 pounds with little pressure differential except in the north part of the area, where a Lewisville pressure is considerably below the average.

It appears that the West Hawkins Dexter oil reservoir is closed and is being produced principally by an expanding gas-cap drive, aided very slightly at this time by a dissolved gas drive. To substantiate this statement, it is pointed out that the original pressure in the West Hawkins Dexter zone was 1,990 pounds as compared with a pressure of 1,710 pounds in the water underlying the Dexter zone. This shows there is an impermeable barrier separating the oil-containing sands of the West Hawkins Dexter from the water-containing sands, which prevented the oil in the Dexter zone from migrating outward under the driving force of the high-pressure gas. Further, there could be no effective water drive acting upon the West Hawkins Dexter zone since the pressure within this zone is still greater than that in the water underlying it. A further clue to the reservoir behavior is given by the fact that a plot of the percentage of pressure depletion versus the percentage of original recoverable oil produced results in a straight-line curve regardless of production rate, which is characteristic of a closed reservoir produced by an expanding gas-cap drive. At a future date, a water drive of some magnitude may develop in the West Hawkins Dexter zone. It would seem, however, since the barrier which prevented movement from the higher-pressured oil- and gas-bearing sands into the water-bearing sands withstood an original differential of 280 pounds, a minimum differential of this amount must be created in a reverse direction before the water could break through the barrier.

Since the Lewisville section is predominantly shale with 30 per cent of the volume occupied by sand lenses, it is unlikely that good communication will be found between all these lenses; and, therefore, neither a satisfactory water nor an expanding gas-cap-type drive is expected. It is interesting to note that all water production to this time is from Lewisville wells, but the pressures in these water-producing wells do not seem to vary markedly from the general pressure trends in the Lewisville zone.

Because of a lack of pressure information, the East Hawkins section of the field has not been studied for a difference in the performance of the Lewisville and Dexter sections. There is considerable evidence that an efficient water drive is acting upon the East Hawkins section of the field.

As mentioned earlier, there had been prior to the time of the discovery of the Hawkins field a general decline in the pressure within the Woodbine basin, and the pressure information immediately following the discovery of the Hawkins field showed that the pressure in East Hawkins had equalized with the pressure in the water underlying it. As further indications of this pressure equalization, both the oil-water and gas-oil contacts had moved downward, allowing the pressures in the oil and gas sands to equalize with the pressure in the water sand. Since the water sand and oil and gas sands are in good communication, the usual active Woodbine sand water drive is expected. To corroborate this thought, a

curve representing the plot of the percentage pressure depletion versus percentage reservoir depletion showed a tendency toward leveling off, even under high fluid withdrawals. With the sharp decline in production at the end of the war, the curve leveled off and showed a slight tendency to trend in the opposite direction though data over a sufficient length of time are not available to support definitely this reversed trend. No substantial water production has been noted in East Hawkins; however, depletion of the reservoir has not reached such a state that substantial water production should be expected.

PRODUCTION

Drilling methods.—The drilling and completion of wells in the Hawkins field have presented very few problems. Some trouble has been experienced with failure to obtain satisfactory primary cement jobs on production strings as evidenced by the producing characteristics of certain wells and the correction of 10 high gas-oil ratio wells by recementing. This condition has been improved to some extent by the use of sand-face scratchers run on the casing.

Drilling practice in the Hawkins field includes setting $9\frac{5}{8}$-inch casing at approximately 1,600 feet, or 100 feet into the Midway shale for protection in case of blow-out and to prevent contamination of the Wilcox and Claiborne fresh-water sands. Five and $\frac{1}{2}$-inch production casing is set through the producing section of the Woodbine. In most of the wells, the lowermost producible oil sand has been gun-perforated so that the heavier oil might be produced during the time of greatest reservoir pressure and at the time when the oil is least viscous because of a greater dissolved gas-oil ratio. It is believed that this practice will result in greater ultimate production than the practice followed in some instances of producing from a large amount of open or gun-perforated section.

On September 1, 1945, only 26 wells of the 405 completions in the field were pumping. With the exception of one completion, all of the pumping wells produce from the Lewisville section. Twelve wells were producing a total of 524 barrels of water per day, all of which produce from the Lewisville section. Analyses of water from the Woodbine show an average of 100,000 parts per million total solids, of which 60,000 parts per million are chlorides.

CRUDE-OIL CHARACTERISTICS

The Woodbine oil produced at Hawkins is exceptional in that it is an asphaltic mixed-base crude and varies in gravity from 16 to 31°. It is brownish black to black in color and contains about 2 per cent combined sulphur.

From a number of samples of the crude brought to the surface under reservoir pressure and restored to reservoir temperature, it has been determined that the average viscosity of the produced oil at the reservoir temperature of 168° F., and the original reservoir pressure varies from 2 to 16 centipoises with an average of 3 centipoises. Likewise, it has been determined that the oil at the gas-oil contact is saturated with gas and has a dissolved gas-oil ratio of from 350 to 400 cubic feet

per barrel of oil. On an average, 100 barrels of oil in the reservoir shrinks to 83.1 barrels in the stock tanks.

PRODUCTION STATISTICS

The following is a tabulation of the production of crude oil from the field.

BARRELS CRUDE OIL PRODUCTION—HAWKINS FIELD

Date	*Production for Period (Barrels)*	*Cumulative Production (Barrels)*
1-1-41	865	865
1-1-42	1,461,052	1,461,917
1-1-43	5,476,276	6,938,193
1-1-44	14,276,403	21,214,596
1-1-45	13,296,279	34,510,875
9-1-45	8,623,738	43,134,613

On September 1, 1945, the field had an oil allowable of 29,885 barrels per calendar day as compared with a maximum of 48,476 barrels during November, 1943.

A cumulative production of 1,896,548 MCF of gas and 15,456 barrels of condensate has been produced from the sub-Clarksville gas reservoir. This gas was used for drilling during early development of the field.

Based on a recovery factor of 41 per cent, it is estimated that the ultimate crude-oil production from the field will be 449,717,500 barrels.

PLANTS AND PIPE-LINE OUTLETS

In April, 1944, a gasoline plant with an intake capacity of 14 million cubic feet of gas per day was put in operation by the Natural Gasoline Corporation, which collects gas from 399 wells, accounting for 99.5 per cent of the produced gas. The plant extracts butane, propane, iso-propane, and 9-pound Reid vapor-pressure gasoline. Residue from the plant is used for drilling and lease fuel with the excess being sold to the United Gas Company.

The price schedule for Hawkins crude is established on a gravity basis and has been, since the first posted schedule, 80 cents for gravities 20° and below, increasing 2 cents per degree to 92 cents per barrel for gravities 25° and above.

The field has two pipeline outlets, one being the Humble Pipe Line Company which transports the major part of the field production, while the other outlet is provided by the Central Pipe Line Company.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 11 (NOVEMBER, 1946), PP. 1857-1874, 11 FIGS.

CORRELATION OF PERMIAN OF WEST TEXAS AND SOUTHEAST NEW MEXICO[1]

JOHN W. SKINNER[2]
Midland, Texas

ABSTRACT

New evidence regarding the age of the San Andres formation is presented, and it is correlated with the Cherry Canyon formation of the Delaware Mountains, the upper part of the Word formation of the Glass Mountains, and the "Blaine of Texas" of the Eastern shelf. The Glorieta formation of New Mexico is correlated with the upper part of the Cutoff member of the Bone Spring formation of the Delaware Mountains, the uppermost beds of the Leonard formation of the Glass Mountains, and the "Holt pay" of north-central Ector County, Texas. The San Angelo formation is correlated with the upper part of the Yeso formation of New Mexico, with beds in the upper part of the Leonard formation of the Glass Mountains, and with the middle and lower parts of the Cutoff member of the Bone Spring formation. The Grayburg formation of the subsurface is shown to be equivalent to the lower part of the Queen formation of the Guadalupe Mountains.

INTRODUCTION

For many years the correlation of the middle and upper Permian has been the subject of considerable controversy. Apparent discrepancies have existed in the paleontological evidence, and rapid facies changes have made the lateral tracing of formations difficult.

When, in 1939, it became desirable to set up a convenient "yardstick" for purposes of regional correlation, a standard section was erected.[3] This standard was based on the evidence available at that time and on the interpretations of the majority of the geologists working on the Permian beds.

However, it was recognized at the time that a number of apparent anomalies remained unexplained which appeared to cast doubt on some of the conclusions set forth. Increased drilling activity in the area and recent field work in the mountains of West Texas and New Mexico have brought to light new bits of evidence that fill in hitherto missing parts of the puzzle. As a consequence, some of the problems can now be solved with a fair degree of confidence. It is recognized that new information will almost certainly necessitate changes in the correlations presented here, but it is hoped that they will be minor in nature and number.

HISTORY OF PROBLEM

Many workers have contributed to our knowledge of the Permian system in this area, but much of the credit must go to Philip B. King who has spent

[1] Manuscript received, February 9, 1946. Read before the Society of Economic Paleontologists and Mineralogists at Chicago, April 4, 1946.

[2] Geologist, Humble Oil and Refining Company. The writer wishes to express his appreciation to Wallace E. Pratt, L. T. Barrow, Morgan J. Davis, and V. C. Maley for their helpful suggestions and criticisms. He is indebted to the Humble Oil and Refining Company for permission to publish this paper. Special thanks are due to Cary P. Butcher who made the aerial photographs used in this article.

[3] John Emery Adams, M. G. Cheney, Ronald K. DeFord, Robert I. Dickey, Carl O. Dunbar, John M. Hills, Robert E. King, E. Russell Lloyd, A. K. Miller, and C. E. Needham, "Standard Permian Section of North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 11 (November, 1939), pp. 1673–81.

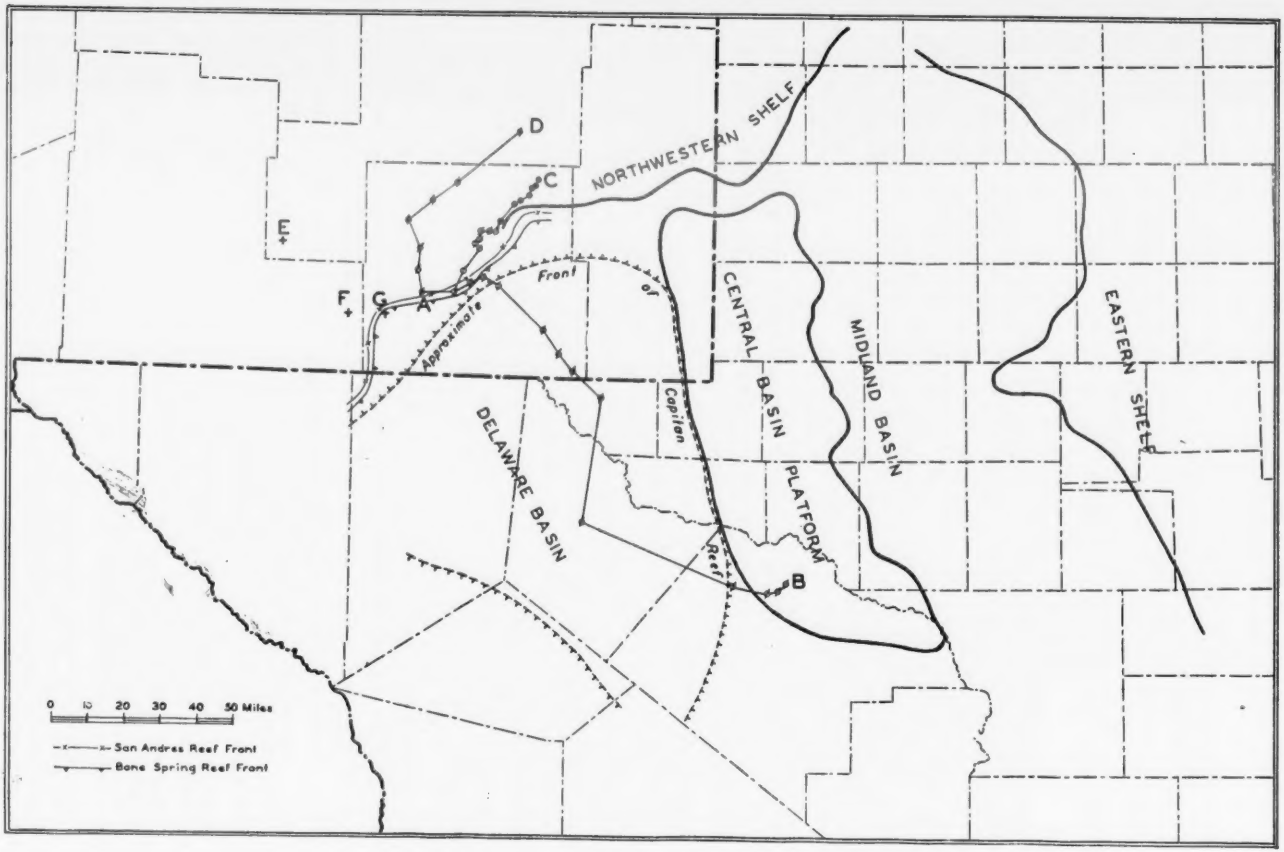


FIG. 1.—Index map of West Texas and southeastern New Mexico.

much time on careful and painstaking work in the mountainous regions which bound the Permian basin on the west and southwest and in which these rocks are well exposed. In addition to a number of reports on individual areas, in 1942[4] he published a paper in which his observations on the various areas were combined in a comprehensive study of the Permian basin as a whole. In this paper the correlations outlined in the standard section were discussed in detail.

King concluded that the lower, or Brushy Canyon, member of the Delaware Mountain group is confined to the deeper basin areas. This idea was based upon the fact that the Brushy Canyon can be seen to lap out against the south side of the Bone Spring flexure which is believed to be a part of the Delaware basin rim. By deduction he concluded that the Brushy Canyon laps out against the rim all around the basin. This theory has been generally accepted, and, with slight modifications, appears to be essentially the case.

Since the basal member of the Whitehorse group, the Grayburg formation, was generally believed to be Cherry Canyon, or middle Delaware, in age and since the Brushy Canyon was present only in the basin areas, it followed that the San Andres formation underlying the Grayburg in the shelf areas must be Bone Spring, or Leonard, in age. This view was supported by the reported presence of *Perrinites* in the San Andres and its occurrence in several zones in the "Blaine of Texas"[5] group, into which the San Andres can be traced through the subsurface. This ammonoid genus was known elsewhere only in beds of Leonard age.

With the foregoing as a basis, the following pattern was developed. The Whitehorse group, with the exception of the Grayburg formation and part of the Queen formation, was correlated with the Carlsbad and Capitan formations of the Guadalupe Mountains, the Bell Canyon formation of the Delaware Mountains, and the Gilliam formation of the Glass Mountains. The Grayburg and part of the Queen were considered equivalent to the Cherry Canyon formation of the Guadalupe and Delaware mountains and to the middle and upper parts of the Word formation of the Glass Mountains. The Brushy Canyon was tentatively correlated with the lower Word. The San Andres was correlated with the "Blaine of Texas" group of the eastern outcrop, the Upper Bone Spring of the Delaware Mountain area, and with the upper Leonard of the Glass Mountains. The lower parts of the Leonard and Bone Spring were considered equivalent to the Yeso formation of New Mexico and to the Clear Fork and Wichita (restricted) of the eastern area. The Glorieta and San Angelo formations were thought to be approximately equivalent and were supposed to be represented by beds near the middle of the Leonard and Bone Spring. The Abo was correlated, in the standard

[4] P. B. King, "Permian of West Texas and Southeastern New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 4 (April, 1942), pp. 535–763.

[5] A. M. Lloyd and W. C. Thompson, "Correlation of Permian Outcrops on Eastern Side of the West Texas Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 945–56. This name was introduced in the discussion on page 954. It is an unfortunate term, but it is the only one in the literature which includes the Dog Creek, Blaine, and Flower Pot formations without also including the San Angelo formation.

section, with the Wolfcamp of the Glass Mountains and with the Hueco of the Sierra Diablo at the western margin of the Delaware basin. King, however, regarded the Abo as being largely post-Wolfcamp in age.

This is the correlation most generally followed by West Texas geologists. However, several apparent anomalies were left unexplained. One of the most vexing of these, for example, was the fact that, in many wells, the subsurface San Andres contained the *Parafusulina rothi* fusuline assemblage which is characteristic of the upper Word, the upper Brushy Canyon, and the Cherry Canyon. The presence of this fauna in the San Andres is hardly in accordance with the supposed Leonard age of that formation.

King recognized these discrepancies, and in his discussion he offered an explanation of them. He suggested that the correlation of these beds with the San Andres might be in error, and in his correlation chart he shows a series of limestones of Brushy Canyon age in the Midland basin. These are depicted as being unconformable with the underlying San Andres and as being confined to the deeper part of the basin. Unfortunately, this explanation becomes unsatisfactory since beds containing Word fusulines can now be traced into the "Blaine of Texas" outcrop which contains *Perrinites*.

In 1941, Frank E. Lewis[6] offered an alternate correlation to reconcile these divergent facts. He considered the Grayburg to be equivalent to the basal Capitan, and correlated the San Andres with the Cherry Canyon and Brushy Canyon. In the Glass Mountains, Lewis extended the use of the term "Word" downward to the conglomerate at the top of the eastern Hess facies of the Leonard, thus including approximately 300 feet of *Perrinites*-bearing beds in the Word. However, the inclusion of *Perrinites*-bearing beds at the base of the Word-San Andres-"Blaine of Texas" still does not account for the abundant presence of this ammonoid in the upper "Blaine of Texas" while it is absent from the upper Word.

PALEONTOLOGY

Gradually, over a period of years, evidence indicating a Word age for the San Andres-"Blaine of Texas" has been accumulating. Since this evidence is chiefly of a paleontological character, it has been counteracted by the presence of *Perrinites* in several zones in the "Blaine of Texas." Those who have favored the idea of a Leonard age for these beds have argued, and reasonably enough, that the ammonoids are among the best guide fossils and that their evidence is as good as any that can be brought against them.

Thus, the whole argument becomes largely a matter of interpretation: which is more reliable in correlations, the first appearance of a new fauna or the last appearance of an old one? Which is more diagnostic, the beginning of a Word assemblage or the end of a Leonard one? Usually, when such apparent discrepancies occur in correlations based on various types of faunas, or between faunal and

[6] F. E. Lewis, "Position of San Andres Group, West Texas and New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 1 (January, 1941), pp. 73–103.

lithologic correlations, certain stock arguments are advanced. These arguments, which are partly contradictory, are as follows.

1. A new species or genus originates in one spot from which it spreads to other areas; hence, the time of its first appearance in any locality depends on the distance of that locality from the point of origin, the relative motility of the organism, and on intervening obstacles.

2. If an unsuitable environment should exist in a certain area, the first appearance of a particular fauna in that area would be delayed until such time as the environment might change to a more favorable one. Thus, for example, if a super-saline sea occupied an area during the early half of Wolfcamp time and then became normally marine, the Wolfcamp marine fauna would make its first appearance at about the middle of the Wolfcamp sedimentary sequence.

3. Fossils can be reworked from older beds and included in sediments younger than the actual range of these species.

4. In some areas a favorable environment may have caused a fauna to persist long after its extinction elsewhere, thus producing paleontological evidence which indicates an earlier age for the containing beds than is actually the case.

Unfortunately, there is enough truth in each of these arguments, if taken by themselves, to cast doubt upon purely paleontological correlations. Let us consider them, one by one.

1. It is true that any new life form ordinarily has its origin in a single individual which, for some reason, has materially departed from the physical norm for its species. This departure may be an abrupt mutation or the cumulative result of many small changes. If this mutant lives and transmits its new characters to its progeny a new species or genus is born. If it is at all motile this new form spreads to other parts of the world, the speed of such spread depending on a number of variable factors such as method of locomotion, adaptability to small environmental changes, and natural obstacles. Actually, the farther from the point of origin the later is its first appearance. However, compared with normal rate of sedimentary deposition, the speed with which even the slowest moving forms spread is very rapid. Even such forms of corals, crinoids, and bryozoans, which spend the greater part of their life cycles anchored in one spot, will extend their geographic range hundreds of miles while only a few inches of sediments are being deposited. Thus, for practical purposes, the initial appearance of a species or genus in a *normal marine sequence* may be considered to be simultaneous throughout its geographic range.

It is believed by some workers that in rare cases a genus or species may be independently evolved at two or more different times or places. Theoretically, this should happen only as a result of identical sequences of external stimuli acting upon a long-lived stock whose characters are so strongly fixed that they persist unchanged over a long period of time. Since so many variables are involved, such regeneration should occur only in very simple life forms, and then only rarely. The odds against the possibility of the independent generation of a faunal *assemblage* are so great that the figures become meaningless.

2. It is true that an unfavorable environment may delay the appearance of a fauna in a particular area, and this fact should be taken into account by the paleontologist. It is also true that such an environment leaves its record in the sediments so unmistakably that it can hardly be overlooked. If, for example, marine Wolfcamp beds are overlain by a barren, non-marine sequence and this, in turn, is succeeded by marine Leonard, the paleontologist will not insist that the abrupt termination of the Wolfcamp fauna necessarily marks the end of Wolfcamp time. Neither will he suppose that the abrupt appearance of Leonard fossils above the barren zone must mark the beginning of Leonard time. In such a case, other means must be employed to determine the proper assignment of the unfossiliferous beds, and until such an assignment can reasonably be made they must be regarded as belonging to both formations, possibly, or to either one.

3. Reworked fossils are by no means unknown. For example, reworked Wolfcamp fusulines are fairly common in the basal conglomerate of the Leonard formation in the Glass Mountains. However, these are almost without exception abraded and broken, while the associated Leonard forms do not show such evidence of wear. In addition, the mere presence of the latter, which do not occur in the underlying Wolfcamp, shows that a major paleontological change has taken place.

4. "Holdover faunas" are not too uncommon. Among the fusulines, for example, several instances are known in which lower Permian types occur high in the Permian section. However, in every such case so far recorded, these are intimately associated with upper Permian species which indicate the true age of the enclosing beds. This is due to the fact that, except for highly specialized or aberrant forms, an environment that is suitable for one species is also suitable for related species. Thus, when changing conditions elsewhere produced mutants and wiped out the old fauna, these new forms quickly spread to surrounding areas, *including the localities in which the "holdover faunas" were still living.* Therefore, these new types are the ones to be considered in evaluating such a mixed fauna.

All these considerations point to one conclusion—the appearance of new elements in a fauna should be given more weight in correlations than should be attached to the continuation of older elements. It is possible for a fossil species or assemblage to persist locally after its extinction elsewhere and thus to give the impression that the enclosing sediments are older than they actually are, but it is obviously not possible for such an assemblage to appear in a sequence *before it has been evolved.* Hence, its presence sets a maximum on the possible age of the enclosing beds. Thus, a Leonard fossil does not preclude the possibility of a *younger* age, but the presence of Word fossils does mean that the containing sediments can not be *older* than Word.

The foregoing remarks apply directly to our Permian correlation problem. For nearly 10 years all of the slowly accumulating paleontological evidence, with two notable exceptions, has pointed to a Word age for the San Andres-"Blaine of Texas," beds. These exceptions are *Perrinites*, which occurs in the "Blaine of

Texas" and *Dictyoclostus bassi* (*Productus ivesi* of authors) which is abundant in the lower San Andres. Both of these fossils have been generally considered to be confined to beds of Leonard age. Opposed to this evidence we have the following.

1. Associated with the "Blaine of Texas" *Perrinites*, Clifton[7] has found *Pseudogastrioceras texanum*, *P. roadense*, and *Agathiceras girtyi*. The first two are not known elsewhere in beds older than Word. *Agathiceras girtyi* is most abundant in the Word, although a few specimens from beds of Leonard age have been doubtfully referred to this species. More recently, Clifton[8] has found *Perrinites* in the lower Word of the eastern Glass Mountains.

2. In the subsurface the San Andres carries *Parafusulina rothi*, *P. lineata*, *P. sellardsi*, and *P. deliciasensis*. On the outcrop these species have heretofore been found only in the Word and its undoubted equivalents.

3. The fossiliferous limestone associated with the "Holt pay" of Ector County, Texas, contains *Parafusulina fountaini* which is known from the outcrop only in the uppermost Bone Spring. The "Holt pay," which underlies the San Andres and overlies the San Angelo, is the highest subsurface zone in which Leonard fossils are known to occur.

4. The Clear Fork is characterized in the subsurface by *Schubertella melonica*, a species which, on the outcrop, is confined by the upper half of the Leonard. In a few wells this same fossil has been found in limestones interbedded with the San Angelo sandstones.

5. Recently, V. C. Maley, W. B. Hoover, M. B. Arick, and the writer spent several days tracing the San Andres of the Sacramento Mountains into the beds which crop out in the west-facing escarpment which forms the east wall of Dog Canyon in the Guadalupe Mountains. In the hills in Sec. 24, T. 19 S., R. 16 E., east of Pinon, New Mexico (see index map, E), there is an excellent exposure of lower San Andres, Glorieta, and upper Yeso. The San Andres here contains an abundance of fossils, including *Dictyoclostus bassi*. The Glorieta is represented by 25 feet of rather coarse, well rounded and frosted sandstone at the top. It is gray, weathering rusty brown, and is partly quartzitic. This is underlain by 33 feet of thin- to medium-bedded dolomitic limestone which is sandy in part. It is believed that these beds, too, are a part of the Glorieta. Between the San Andres and the Glorieta is about 8 feet of coarse limestone conglomerate. Below the Glorieta limestone, apparently conformably, lie typical Yeso red, yellow, and gray shales and gypsum.

These beds are exposed in a continuous escarpment from this locality to Dog Canyon. The section was examined and the Yeso, San Andres, and Glorieta identified at the following localities: Sec. 34, T. 19 S., R. 17 E.; Sec. 18, T. 20 S.,

[7] R. L. Clifton, "Paleoecology and Environments Inferred for Some Marginal Middle Permian Marine Strata," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 7 (July, 1944), pp. 1012–31.

[8] R. L. Clifton, "Permian Word Formation: Its Faunal and Stratigraphic Correlatives, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 12 (December, 1945), pp. 1766–76.

R. 18 E.; Sec. 30, T. 20 S., R. 18 E.; Sec. 7, T. 21 S., R. 18 E.; Sec. 1, T. 22 S., R. 18 E.; and Sec. 20, T. 23 S., R. 20 E.

The San Andres changes little along the escarpment, except that the section thickens southeastward by the addition of upper beds which have been eroded away in the northern area. The lower part of the formation commonly forms massive cliffs.

The upper Glorieta sandstone thins progressively southeastward along the escarpment, and at the last locality is only about 10 feet thick. It is less quartzitic than it is at the northwest, and it weathers yellow instead of brown. It is still coarse-grained, and the grains are well rounded and frosted. Due to slumping of the overlying San Andres limestone it is covered in many places, but in clean exposures it appears as a thin but prominent yellow zone immediately beneath the San Andres cliffs. Conglomerate between the two formations was observed at only the one locality.

The dolomitic limestone section, which was observed beneath the Glorieta sandstone at the first locality and which is here considered to be lower Glorieta, apparently grades laterally into red and gray gypsiferous shales with thin dolomites interbedded here and there. This zone thickens southeastward, and, while in the last exposures it can not be separated with certainty from the underlying Yeso, it apparently attains a thickness of about 200 feet in Dog Canyon.

The Yeso makes up a little more than the lower half of the escarpment for most of the distance. Dolomitic limestones become more important southeastward, and from near the center of the east line of T. 20 S., R. 17 E., to near the south line of T. 21 S., R. 18 E., a zone of limestones makes a prominent bench about midway up the escarpment. This sequence of limestones is about 150 feet thick, and its top is approximately 200 feet below the base of the San Andres. It consists of white limestone at the base overlain by dark, cherty limestones with a brown, cross-bedded, coarse-grained, dolomitic sandstone at the top. The writer regards this sandstone as the top member of the Yeso. From a distance this sequence appears as a dark band along the face of the escarpment, and it can be followed for miles. The cherty limestones of the group superficially resemble the San Andres, but fossils are rare, though they are abundant in the San Andres.

The shales of the Yeso become more gypsiferous southeastward, and the color changes from predominantly yellow and red to predominantly gray. These shales characteristically weather into steep slopes nearly barren of vegetation.

Finally, the section exposed in the Dog Canyon scarp in Sec. 3, T. 24 S., R. 20 E. (see index map, F), was examined in considerable detail. The San Andres at this locality can be divided into two members, the upper of which is made up of medium- to heavy-bedded dolomitic limestones which weather light gray or nearly white. These limestones have a fine texture and weather to a smooth surface. Fusulinid casts and molds are abundant in the lower part of the member, which is about 550 feet thick, but they are too poorly preserved for specific identification. The lower member consists of approximately 350 feet of heavy-

FIG. 2.—Part of south-facing escarpment in southeastern Sacramento Mountains in Sec. 24, T. 19 S., R. 16 E. View looking east. *Ps*, San Andres; *Pg*, Glorieta; *Py*, Yeso.

FIG. 3.—Canyon cutting through south-facing scarp of Sacramento Mountains in Sec. 34, T. 19 S., R. 17 E. View looking west. *Ps*, San Andres; *Pg*, Glorieta; *Py*, Yeso.

FIG. 4.—View eastward toward northern part of west-facing scarp of Guadalupe Mountains. Prominent hill at left is in Sec. 18, T. 20 S., R. 18 E. *Ps*, San Andres; *Pg*, Glorieta; *Py*, Yeso.

FIG. 5.—View eastward toward Guadalupe escarpment. This area is about 2 miles south of that shown in Figure 4, and shows section exposed in Sec. 30, T. 20 S., R. 18 E. Here, sandstone at top of Glorieta is only about 20 feet thick, and lower Glorieta dolomites have begun their gradation into gypsiferous shales with attendant thickening of section. *Ps*, San Andres; *Pg*, Glorieta; *Py*, Yeso; *X*, cross-bedded dolomitic sandstone which caps prominent bench at top of the Yeso.

FIG. 6.—View of Guadalupe scarp just north of mouth of Dog Canyon in Sec. 1, T. 22 S., R. 18 E. Hills in foreground have been faulted down. Sandstone at toy of Glorieta has thinned to 10 feet, and lower Glorieta has become so similar to Yeso that the two can not be separated with certainty. *Ps*, San Andres; *Pg*, Glorieta sandstone; *Py*, Yeso.

FIG. 7.—East wall of Dog Canyon in Sec. 3, T. 24 S., R. 20 E. At this locality Glorieta sandstone was not seen, and Glorieta-Yeso contact can not be determined. Lower part of San Andres contains abundant Word fusulinids. *Ps*, San Andres, *Py*, *Yeso*.

bedded to massive, cherty, dolomitic limestones which commonly form prominent cliffs. The limestones of this member are relatively dark-colored and weather to a rough surface. Chert nodules and concretions are abundant and the lithology is closely similar to that of the lower San Andres near Pinon. In the chert are abundant well preserved fusulines among which *Parafusulina sellardsi*, *P. lineata*, *P. rothi*, and *P. deliciasensis* have been identified.

Beneath the fossiliferous San Andres lies a sequence of 200 feet of thin- to medium-bedded dolomites interbedded with sandy gypsites and shales. The upper Glorieta sandstone was not seen at this locality and its apparent absence might be accounted for in several ways. Three explanations should be considered.

a. It is present but covered by slumping of the overlying beds, as observed farther northwest.

b. It is absent due to pre-San Andres erosion.

c. It has graded laterally into Yeso-like beds and can no longer be identified.

The writer is inclined to consider the third explanation as most probable. In the subsurface on the northeast the same southward thinning and disappearance of this sandstone can be observed. At the same time, the interval from the top of the Glorieta down to the top of the first San Angelo sandstone thickens southward toward the basin. While this does not preclude the possibility of removal by erosion, it strongly suggests lateral gradation.

The sequence observed here beneath the San Andres can not be certainly separated from the Yeso, but the writer believes it to be the approximate equivalent of the Glorieta dolomitic limestones at the north and of the 200 feet of fossiliferous limestone at the top of the Bone Spring in the Spearow's McClelland No. 1 on the east. These beds, in turn, rest on typical Yeso sandy shale, gypsum and thin-bedded dolomites.

6. Approximately 11 miles due east of this locality, in Last Chance Canyon just above its confluence with Sitting Bull Canyon (index map, G), the lower member of the San Andres is exposed resting unconformably on limestones which contain a Bone Spring fauna. Here, the San Andres is sandy nearer the basin, or Cherry Canyon, facies, but the cherty character and the fusuline fauna remain unchanged. The upper member is absent, or very thin, and there appears to be an angular unconformity between the San Andres and the overlying Queen formation. It is believed that this unconformity has only local significance. The Queen contains a few specimens of *Polydiexodina shumardi*, a species that is characteristic of the Capitan formation and its equivalents.

The foregoing may be summarized as follows. The San Andres-"Blaine of Texas" contains an assemblage of Word fossils both in the subsurface and on the outcrop. In the subsurface it is underlain by beds containing uppermost Bone Spring, or Leonard, fossils. On the outcrop it is underlain by beds containing Leonard fossils and overlain by sediments which contain a Capitan fauna. From this, one can hardly escape the conclusion that the San Andres-"Blaine of Texas" is Word in age and that the Leonard elements in the fauna are "holdovers."

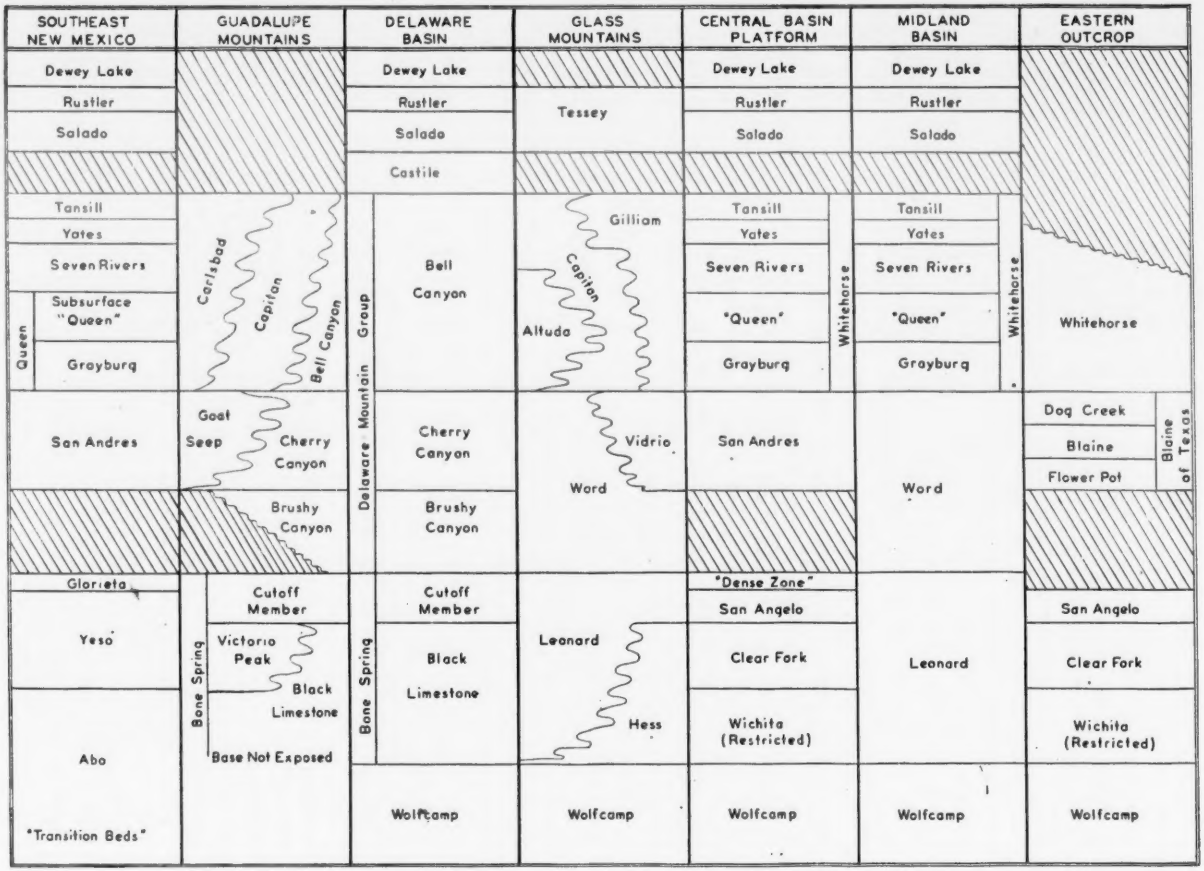


FIG. 8.—Correlation chart of Permian formations.

CORRELATIONS

Lithologic correlations have, in the past, been hampered by the rapid changes in facies of the Permian formations. Only recently have enough deep wells been drilled to overcome this handicap to a large extent, and even now exact correlations are more or less uncertain in many places.

In general, four facies can be recognized, although a single formation may not necessarily display all of them. These are a "basin" facies, ordinarily consisting of dark limestones, sandstones, and black shales; a "slope" facies, composed of light to dark, relatively dense, commonly silty limestone; a "reef" facies, consisting of massive, light-colored, commonly crystalline dolomite or limestone; and a "shelf" or "platform" facies, made up of thin-bedded dolomite or limestone near the reef, grading into evaporites and red clastics away from the reef.

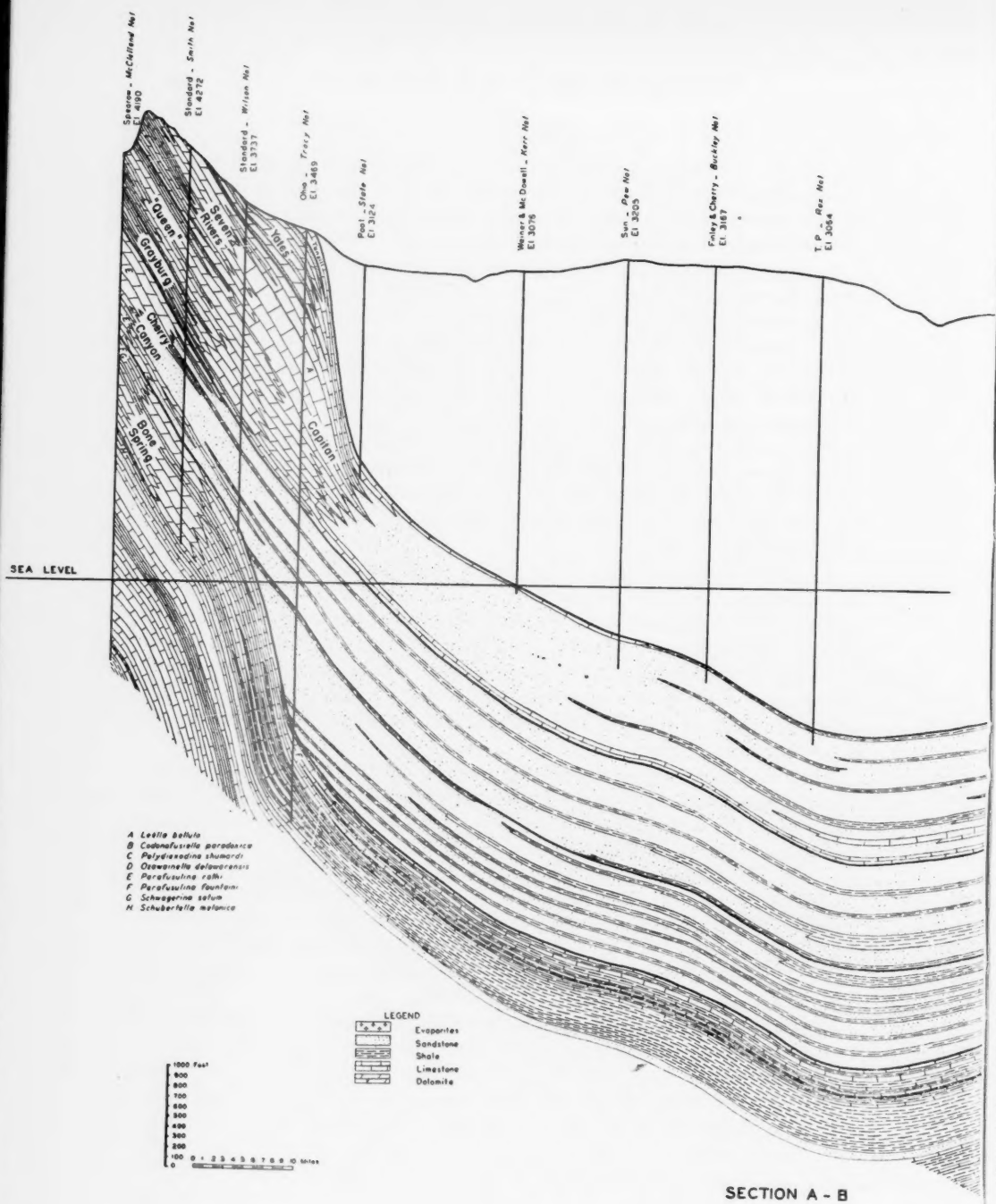
The change from one facies to another commonly takes place in an amazingly short distance, so that breaks in the continuity of exposures are in many places difficult to bridge. However, once the Word age of the San Andres-"Blaine of Texas" is accepted, many parts of the correlation puzzle begin to fall into an orderly pattern.

Recent field observations and subsurface studies strongly suggest that the Grayburg formation of the subsurface is nothing more than the lower part of the Queen formation of the outcrop, while the "Queen" of the subsurface is apparently the upper part of that formation. Indeed, it appears probable that Queen postoffice, the type locality of the Queen formation, is located on the Grayburg outcrop. If this is true, since the name "Queen" has a priority of many years the Grayburg must be reduced to the rank of a mamber of the Queen formation, if the term is to be retained at all.

Since the basal Queen of the outcrop, and therefore the basal Grayburg, contains Capitan fossils, and since a Capitan fauna has been found in the Tansill formation at the mouth of Dark Canyon southwest of Carlsbad, New Mexico, it is concluded that the entire Whitehorse group must be correlated with the Capitan formation and its equivalents and that no part of this group is as old as Word.

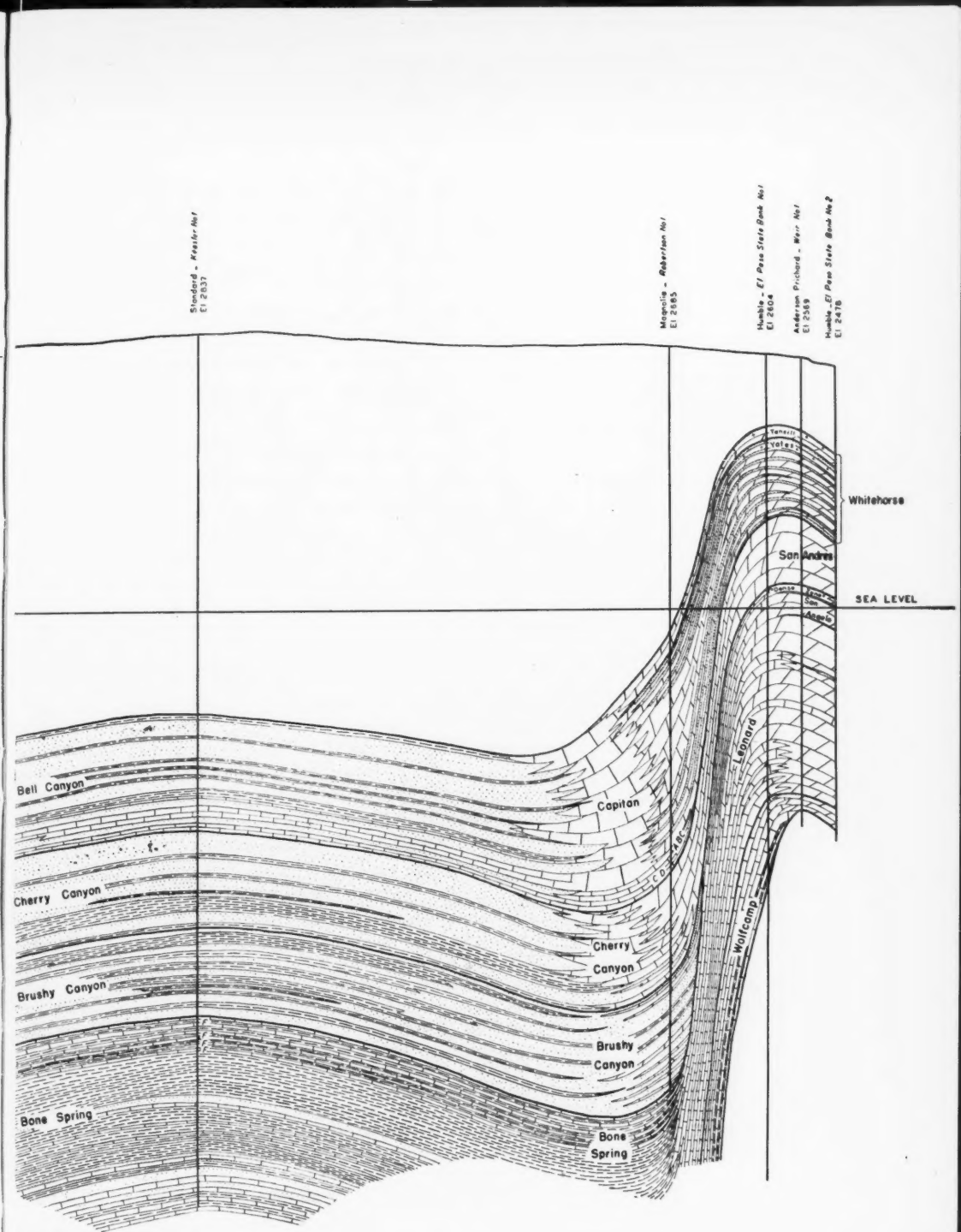
The Word age of the San Andres-"Blaine of Texas" seems to be well established, and the fusuline fauna strongly suggests that it is *upper* Word. Subsurface studies appear to bear this out and to indicate equivalence to the Cherry Canyon formation of the Delaware Mountains. The Brushy Canyon, as suggested by King, is apparently confined to the basin areas.

The uppermost Bone Spring of the Delaware Mountains area consists of the Cutoff shaly member which bears a strong resemblance to the uppermost Leonard of the eastern Glass Mountains. The latter is separated from the underlying Hess limestone facies of the middle and lower Leonard by a locally prominent conglomerate. This sequence of limestone and shale with a basal conglomerate is, in turn, similar to the San Angelo. As nearly as can be determined at present, the top of the Bone Spring falls, in the shelf or platform areas, at about the top of the so-called "Dense zone" which immediately overlies the highest San Angelo



SECTION A - B

FIG. 9.—Cross section from Carlsbad Hills to Ce



to Central Basin platform.

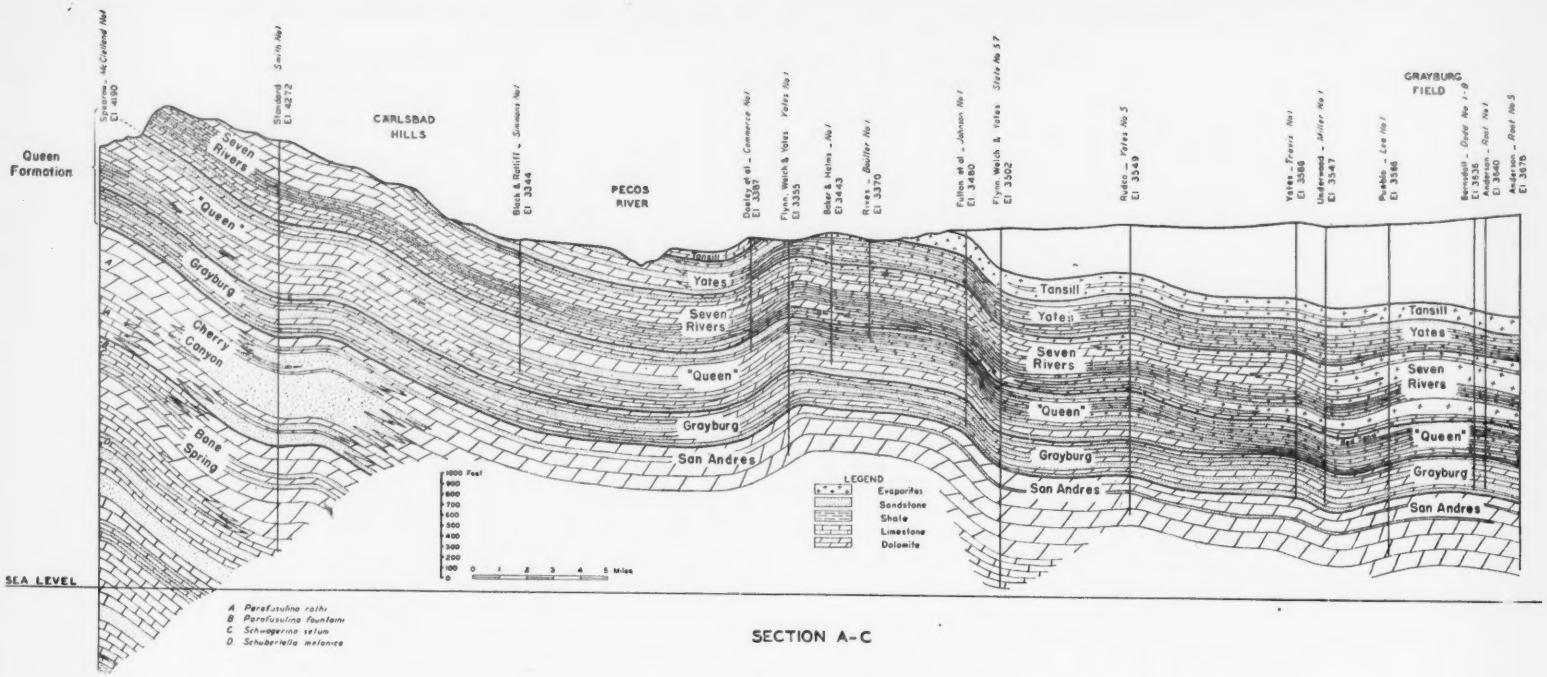


FIG. 10.—Cross section from Carlsbad Hills to Grayburg field.

sandy beds. This "Dense zone," which appears to be equivalent to the previously mentioned "Holt pay" of Ector County, may be correlated with the uppermost San Angelo of the eastern outcrop, but present evidence suggests that it, together with the Brushy Canyon, is represented by a hiatus between the San Angelo and the Flower Pot. No physical evidence of such a break has ever been reported in the eastern outcrop area, but this does not disprove its presence. It is known that even greater breaks display no physical sign of their presence. Thus, the absence of upper Silurian between the Haragan and Henryhouse members of the Hunton of Oklahoma is known only on faunal evidence. There is no physical evidence known of a hiatus between the Tansill and Salado in the shelf areas of West Texas, and yet the Castile lies between these two formations in the Delaware basin while it is absent on the shelf.

The southernmost extension of the Glorieta sandstone falls in the upper part of the "Dense zone," and it may be that the entire zone is merely the carbonate facies of the Glorieta. If such is the case, the upper part of the Glorieta maintains its sandstone facies farther southeast than the lower part. The uppermost Yeso sandstones can be traced, in the subsurface, into the upper sandstones of the San Angelo. Thus, it appears that the Glorieta plus the upper Yeso is equivalent to the Cutoff member of the Bone Spring.

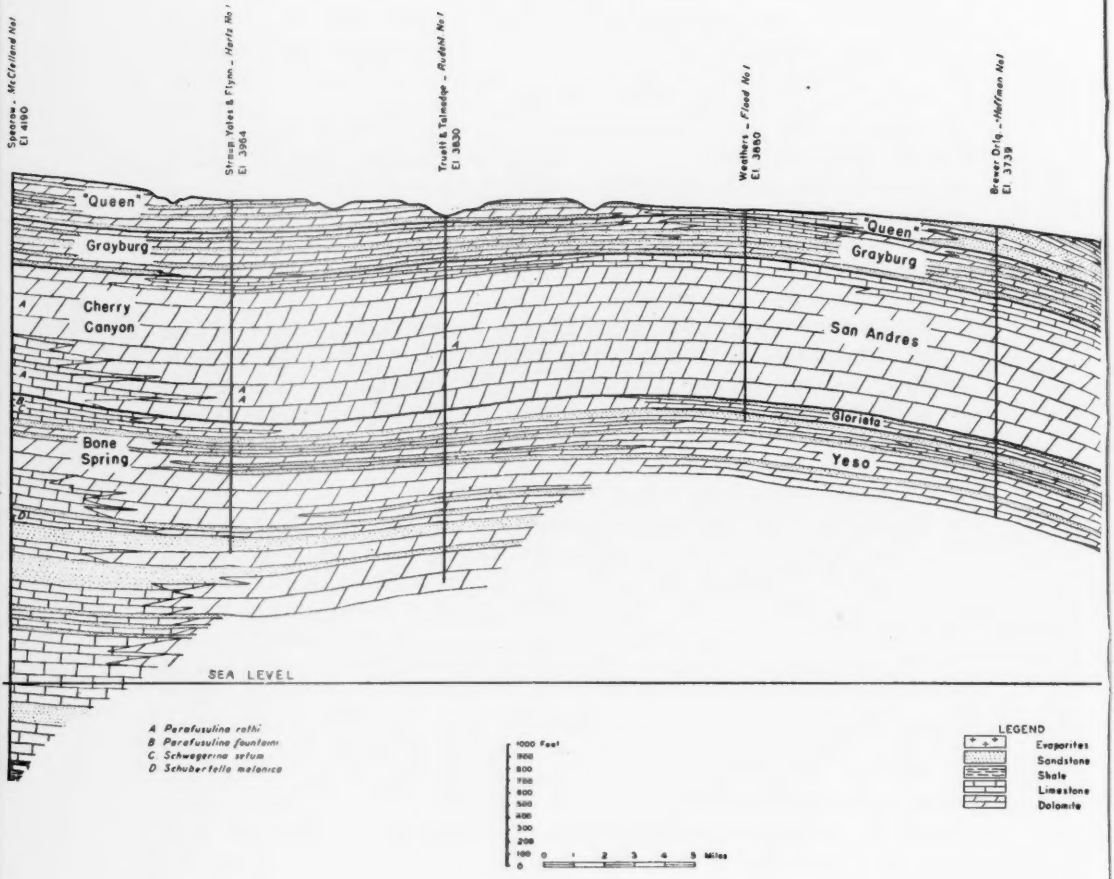
The top of the Abo of New Mexico apparently is closely correlative with the top of the Wichita of Texas. The base of the Abo has, in the past, been regarded as the base of the Permian, but recent work by New Mexico geologists indicates that this conception may be in error. The lower part of the sequence which has heretofore been called Abo contains fossiliferous limestones interbedded with red, Abo-like shales and sandstones. The geologists of the New Mexico School of Mines refer to this section as the "Transition beds," and reserve the term "Abo" for the redbeds above the highest limestone. These "Transition beds," which contain a Wolfcamp fusuline fauna, correspond with the Hueco of R. E. King.[8]

The Abo, thus restricted, is correlative with the lower Leonard and upper Wolfcamp of the Glass Mountains. Since it is a lithologic unit with no marine fossils, it is impossible at present to determine the Leonard-Wolfcamp contact. It is interesting to note that farther east, in the northern shelf area in Texas, this same sequence is still a lithologic unit although it has changed to the carbonate facies. Thus, it is easier to separate the lower Wolfcamp from the upper Wolfcamp than it is to differentiate between the upper Wolfcamp and the lower Leonard.

CROSS SECTIONS

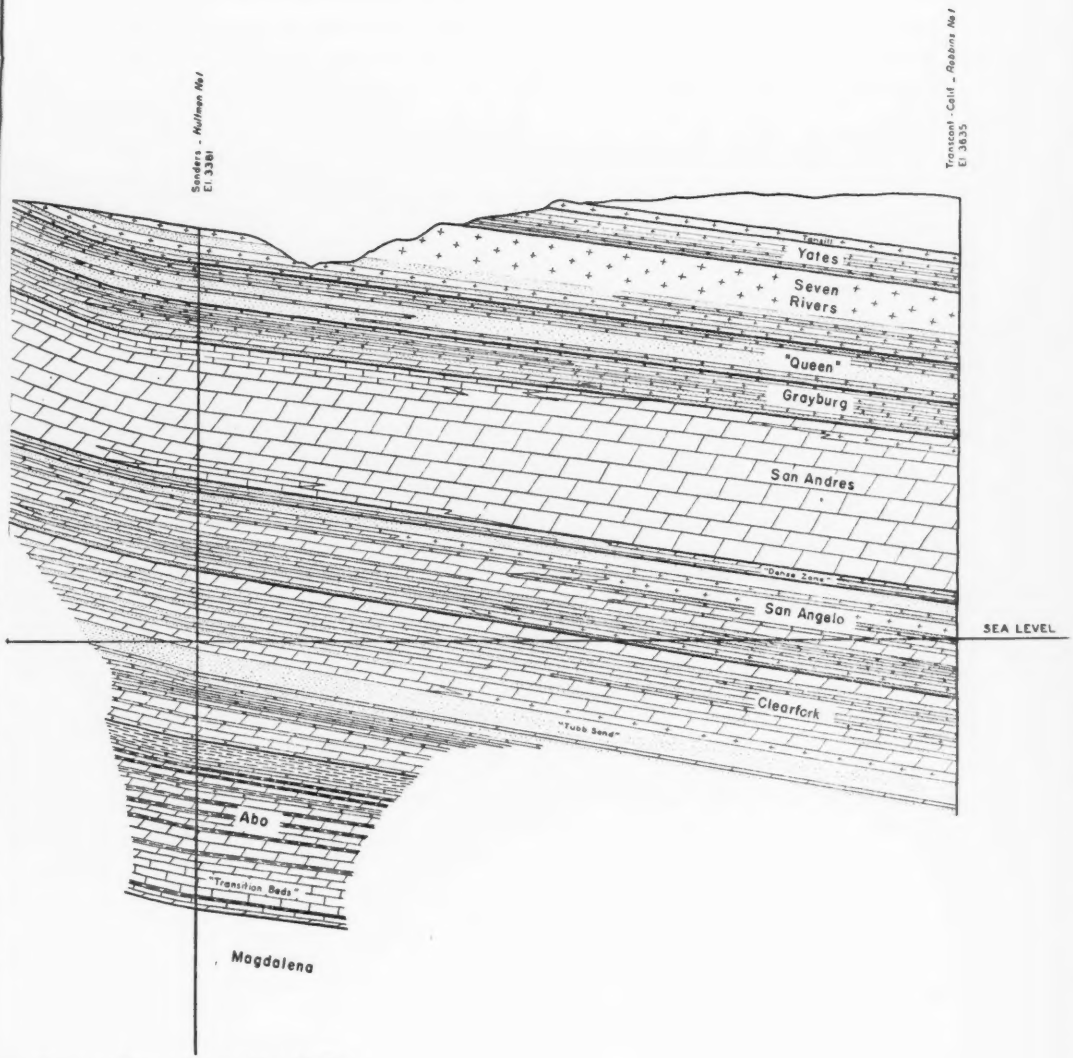
The accompanying cross sections show, graphically, the writer's present views on the correlation of the Permian, and this information is summarized on the correlation chart. These three sections begin at a common point, the Spearow's McClelland No. 1, located in the hills southwest of Carlsbad, New Mexico. This

[8] R. E. King, "Stratigraphy and Oil-Producing Zones of the Pre-San Andres Formations of Southeastern New Mexico," *New Mexico School of Mines Bull. 23* (1945).



SECTION A-D

FIG. 11.—Cross section from Carlsbad Hills to so



to southeastern Chaves County, New Mexico.

well has been selected as a starting point because it can be correlated both lithologically and faunally with the near-by outcrops. The trace of the sections and the approximate outlines of the main structural features are shown on the index map. Since this discussion is concerned only with the beds between the top of the Tansill and the base of the Permian, only the formations between these two horizons are shown on the cross sections.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 11 (NOVEMBER, 1946), PP. 1875-1887, 3 FIGS.

NORMAL FAULT STRUCTURES AND OTHERS[1]

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ABSTRACT

This paper emphasizes the importance of shearing as a kind of deformation which is often confused with folding. It presents a type of normal faulting as a mountain-making effect due to uplift against gravity. The structure of the Colorado plateaus is taken as the type. Basin-range faulting is regarded as closely similar. The mechanism of normal faulting is analyzed and it is shown that one result is lateral expansion, which produces compression where tension is usually assumed. Normal-fault provinces are briefly described. The description is extended to the structures of the Rocky Mountains in Wyoming and to the rift structures of California.

COLORADO TYPE

In their surveys of the Colorado plateaus Powell,[3] Gilbert,[4] and Dutton[5] recognized that normal faulting is the typical structure of the plateaus and that it is genetically related to monoclinal flexures. They traced the faults into flexures and the flexures into faults.

Faults in the Colorado plateaus are many miles in length, up to 300, and they exhibit throws of as much as 2,000 to 3,000 feet. The north-south strikes are roughly parallel but in some instances they converge and join. The hades of the faults are steep, commonly between 70° and vertical. Parallel faults may hade in the same direction, constituting a series of steps; or they may hade toward the intervening strip, producing a graben; or they may hade away from each other, defining a relatively raised block or horst. In some zones of relatively limited extent numerous faults and monoclinal flexures divide the strata into small blocks, which may be raised or depressed with regard to one another and more or less tilted. Powell called them "zones of diverse displacement."

It is a common assumption that normal faults result from a horizontal tensile stress, but there are many instances in which the assumption is contradicted by evidence of compression. In the type locality, the Colorado plateaus, pronounced flexing of the strata demonstrates lateral pressure, as described by Walcott,[6] and the fact that the intrusive igneous rocks, which occur abundantly in the Plateau province, do not appear in the faults, indicates that the latter were tight, not open as they would have been in tension. Compression results from the mutual pressure of wedge-shaped blocks when displaced by vertical forces.

[1] Manuscript received, May 11, 1946.

[2] Stanford University. This paper is a product of the Distinguished Lecture tour of 1945 and is an outcome of the information courteously given by members of the American Association of Petroleum Geologists, to whom the writer gratefully tenders his thanks.

[3] J. W. Powell, "Geology of the Uinta Mountains," *U. S. Geol. and Geogr. Survey of the Territories* (1876), pp. 14–17.

[4] G. K. Gilbert, "The Colorado Plateau Province as a Field for Geological Study," *Amer. Jour. Sci.* (3), Vol. XII (1876), pp. 16–24 and 85–88.

[5] C. E. Dutton, *Geology of the High Plateaus of Utah* (1880), pp. 25–54.

[6] C. D. Walcott, "Study of a Line of Displacement in the Grand Canyon of the Colorado," *Bull. Geol. Soc. America*, Vol. I (1890), pp. 49–64.

The uplift of the Colorado plateau to 7,000 feet or more above sea-level has taken place in Pliocene and Pleistocene time and is probably now in progress. It has long been recognized that the earth's surface rises and subsides. Benjamin Franklin observed marine shells in the hills of England and he heard of coal mines beneath sea-level. He drew the obvious conclusion. Subsidence is attributed to gravity, a universal attraction. Uplift is a contrary effect and, since we can not suppose gravity to have been suspended, it must be due to some force stronger than gravity. Edouard Suess denied the existence of such a force and reasoned that all differences of level must be due to subsidence, but William M. Davis[7] proved the error of that argument by pointing out that there are peneplains which have been raised high above the level at which they could have been eroded. The question is now an academic one, since the fact of uplift is very generally recognized.

Vertical changes of level of the earth's surface are commonly accompanied by normal faulting. Under certain conditions the relation is a mechanical effect that is quite as logical as the development of thrust faults by horizontal compression.

MECHANICS OF UPLIFT

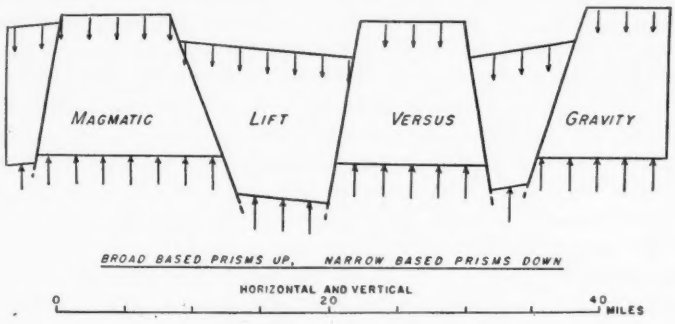
We assume a lifting force stronger than gravity acting under a broad, but not unlimited area of the earth's surface. The dimensions of the area are those of plateaus or plains, some tens of miles across or perhaps several hundred, but not of indefinite extent. Beneath such an area there are, by hypothesis, conditions of some sort that occasion a lifting force and the limits of the area are simply those of the action of that force.

Whatever the cause of the lifting force, the assumption on which we proceed is that it acts vertically upward from such a depth that the load is sufficient to produce shearing on definite planes. There is a less depth, at and above which the weight is too light, and fracture, if it occurs, is irregular. And there is a greater depth, at and below which load and high temperature result in the flattening and reorganization of crystalline structure. Shearing is there a common form of deformation, but the shearing planes approach a horizontal attitude. The zone of *high-angle* shearing is intermediate in position and relatively moderate in conditions of temperature and load. It is therefore a definitely limited layer a few miles thick (Fig. 1).

Furthermore, displacements can occur only if the foundation is so mobile that gravity can depress the narrow-based segments or that the supporting rock can rise beneath the wide-based segments that it forces up. This means that the foundation must be highly plastic, potentially molten, or actually melted. The very common occurrence of intrusives and extrusives in the Colorado plateaus and Basin-Range districts indicates the presence of magma below the outer crust in those cases. Where major normal faults have been developed, yet surface evi-

[7] W. M. Davis, "The Bearing of Physiography on Suess's Theories," *Amer. Jour. Sci.* (4), Vol. 19 (1905), pp. 265–73.

dences of magma are lacking, it may be thought that the molten mass lies at great depth or that some other condition has determined the faulting. The latter is the case with the Nemaha granite ridge in Kansas. That notable linear uplift, bounded by a normal fault, may perhaps indicate the boundary of a provincial mass that has been forced up, while the adjacent body has lagged behind or subsided. The cause of uplift is obscure from lack of evidence. It might resemble that of the Basin-Range structures or more likely be of the class of changes that persistently raise the positive continental elements, such as the Laurentian high-



NORMAL FAULTING
GREAT BASIN TYPE
FIG. 1

lands. Broad, epeirogenic uplifts of that nature are presumably due to increase of volume of crystalline masses or shells forming the lower part of the crust, in consequence of an adjustment of minerals to an environment of lowered pressure. Fermore's[8] concept of intraplutonic and plutonic zones is here suggested, the condition of lowered pressure upon the minerals being caused, in the writer's thought, by the lift and erosion over a still deeper-seated magma bubble. However, in such epeirogenic uplifts normal faulting is rare or absent and the discussion may not go beyond the suggestion of a condition other than the presence of magma beneath the upraised layer.

In the thick layer of crust compressed between gravity and the lifting force the potential shear planes should develop according to the mathematical principles governing shearing. If the mass were not otherwise stressed they would take an attitude of 45° to the vertical and horizontal; but under the assumed conditions of excessive load horizontal stresses are usually set up and they cause a rotation of the shearing planes toward the vertical. They are commonly so effective that the shears develop with a dip of 70° or more and may approach the vertical.

[8] L. L. Fermore, "Preliminary Note on Garnet as a Geological Barometer and on an Infra-Plutonic Zone in the Earth's Crust," *Records Geol. Survey India*, Vol. 48, Pt. I.

Under the assumed conditions the shearing starts at the bottom and progresses upward, dividing the layer into rhomboidal blocks. Theoretically we might expect them to be equally spaced, but that is assuming a homogeneous medium, a condition not commonly present in the heterogeneous crust. An older structure, such as schistosity, will ordinarily promote the development of one set of shears in preference over others and that shearing will divide the layer into strips, which will have a common strike and extend in a parallel structure, with minor cross faults.

The strips thus cut out by the steeply inclined shears will have the form of wedges in any vertical cross section. Some will have narrower, some comparatively wide bases at the level at which the lifting pressure initiates shearing. The proportion of mass to area of base will differ accordingly. Segments with a broad base will have a proportionately smaller load to lift per square mile of lifting pressure, whereas those with a narrower base will have the proportionately larger mass above. It follows that the former will be pushed up, while the latter will tend to sink down in response to gravity. Sir Archibald Geikie first stated this principle of normal faulting in his *Textbook of Geology* in 1893. It is herein accepted as a general condition of major normal faulting.

Since under the assumed conditions the shearing is initiated by the lifting pressure at some considerable depth below the surface, it follows that the structure may be independent of surface features or be influenced by them only in minor degree. It may be expected to have developed in any broad uplift, whether the surface relief be that of a plateau or of a plain. The faulting may be very widely spaced and have produced only a single ridge or it may be so narrowly spaced as to give rise to parallel ranges, such as those of the Great Basin. The action may have occurred at any time in the geologic past or present. And the general condition of uplift may have been replaced by subsidence, resulting in the occurrence of normal faults in a basin area.

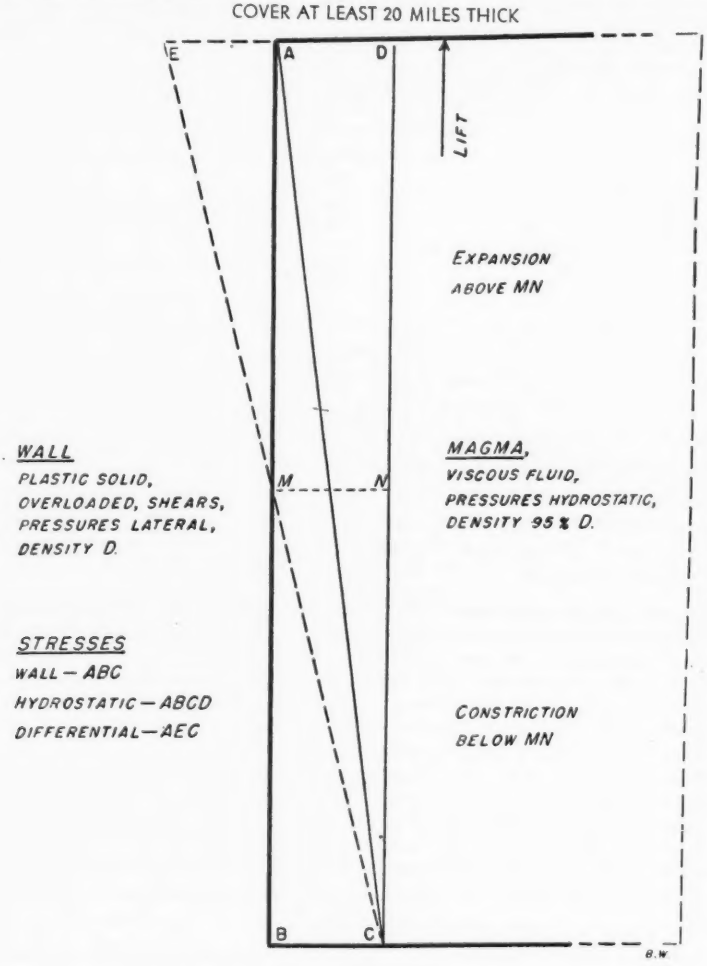
Since the lifting pressure of magma is an essential postulate of this discussion it becomes desirable to indicate the mechanics of that problem. Why and with what degree of stress does magma press upward?

Figure 2 presents a hypothetical, cylindrical magma body, that artificial form being chosen because it lends itself to a simple analysis of the stresses involved. Such a body is enclosed by a wall of solid rock and the density of the magma may be taken at approximately 95 per cent of that of the wall. It is further assumed that the load upon the wallrocks is in excess of their strength and that they are therefore plastic, though solid.

Under these conditions the wall presses against the magma with a slightly greater stress than that exerted by the magma against the wall and the excess wall pressure may be indicated by the triangle *ABC*. It is zero at the top and a maximum, *BC*, at the bottom.

The maximum *BC* being exerted against a viscous liquid, is transmitted by the liquid body hydrostatically to the walls and cover. It is represented by the

rectangle *ABCD*. At any level it is opposed by the excess wall pressure and there is a differential, represented by *ACD* or *ACE*. The form of hypothetical, cylindrical body would be altered accordingly. And the hydrostatic pressure of the magma would be exerted vertically to raise the cover, the lift being proportioned to the depth of the magma below it.



STRESS DIAGRAM OF A MAGMA BUBBLE

FIG. 2

NORMAL FAULT PROVINCES

The type area for major normal faults is that which has been made classic by the descriptions by Powell, Gilbert, and Dutton—the Colorado plateau. The characteristic structures are, however, of widespread occurrence and they serve to identify provinces in which a vertical lifting force has produced the structure.

Normal-fault provinces are frequently confused with zones of major folding, but it is most desirable to differentiate the two, not only in the discussion of terrestrial dynamics, but also in economic practice. They may be differentiated as follows.

STRUCTURAL PROVINCES

Normal Fault Type	*Folded Type*
Plains or plateaus, eroded to a peneplain or covered with flat-lying sediments	Ridge and valley, Appalachian type
Major (primary) normal faults. Minor (secondary) folds and high-angle thrusts	Major (primary) folds anticlines, synclines and low-angle thrusts. Minor (secondary) normal, diagonal or transverse faults, commonly entirely lacking

A few well known examples of the normal-fault provinces of the United States are briefly described in the following paragraphs.

Central New Mexico presents a typical basin-and-range structure in the Tularosa valley and the bounding ranges, the San Andrés on the west (Long. 106°30′) and the Hueco on the east (Long. 106°). The valley, which is 30 miles across, appears on the surface as a synclinal flexure, presumably covering a downfaulted block. The two ranges are monoclinal uplifts, dipping away from one another and defined along their outer margins by major normal faults. The structure is interpreted in Fig. 1. The example illustrates a general condition described by Lindgren[9] in part as follows.

Mountain building accompanied and succeeded intrusion. While conditions still remained quiescent in eastern and northwestern New Mexico, tremendous forces were at work in the southward extension of the Rocky Mountain region. The old pre-Cambrian core in the north seems to have been forced upward by faulting, or by warping followed by faulting. Farther south the sediments were broken along north-south lines and the characteristic New Mexican monoclinal ranges were created, the prototype of the "Great Basin structure," which in fact is far more characteristically developed in this region than in the area from which it receives its name. Knowledge concerning the mechanics of this mountain building is somewhat uncertain, and the purposes of this report do not require their detailed discussion. It is sufficient to say that the Sandia, Oscura, San Andrés, Caballos, Organ, and other ranges, which lie in the southern continuation of the Rocky Mountain uplift, clearly show this combination of a fault scarp, facing east or west, with a monocline sloping gently in the opposite direction. Folding is absent or only slightly developed.

Charles L. Baker,[10] in the latest available publication regarding the structure,

[9] Waldemar Lindgren *et al.*, "The Ore Deposits of New Mexico," *U. S. Geol. Survey, Prof. Paper 68* (1910), pp. 32–33.

[10] C. L. Baker, "Tectonics of the Sierra Andres of New Mexico," *Pan-Amer. Geologist*, Vol. 75 (1941), pp. 53–56.

states that the San Andrés range is defined by longitudinal normal faulting, which has produced the tilted block, and exhibits numerous cross faults, associated with lateral displacements, folds, and even overthrusts. The range thus exhibits a typical example of the association of major normal faulting with minor effects of folding.

In California, Nevada, Oregon, and Utah the basin-range structure occurs typically developed in intimate and protean association with the most diverse structures. The phenomena are too complex to be discussed in detail in this connection, but the major role played by normal faulting places the province in the category of those under discussion and makes it appear that probably some part of the compressive stresses, whose effects are there observed, may be due to the action of gravity and uplift in driving wedges vertically. The pressure of igneous intrusion and the absence of friction at the base of a crustal segment if supported on molten magma have presumably been effective in producing and promoting horizontal displacements. Even normal faulting of the landslide type and the inertia of the sliding mass seem to have played a part. However, it suffices the present purpose to classify Basin-Range structure as primarily of the normal-fault type, occasioned by vertical uplift, as Gilbert[11] stated in 1875. His description and characteristically cautious interpretation are classic and should be read as a whole, but two significant paragraphs are quoted.

> The movements of the strata by which ridges have been produced have been in chief part vertical along planes of fracture, and have not involved great horizontal compression. There are some notable local exceptions to this, but considering the prevalence of faulted monoclinals, which demand no horizontal motion, the existence of the feature as a distinctive one need not be questioned.
>
> We may say, without fairly entering the field of speculation, that the forces which have been concerned in the upheaval of the basin ranges have been uniform in kind over large areas; that whatever may have been their ultimate sources and directions, they have manifested themselves at the surface as simple agents of uplift, acting in vertical or nearly vertical planes, and that their *loci* are below the immediate surface of the earth's crust.

Eastward from the Rocky Mountain front, stretch the High Plains, extending south from Canada to Texas. Being mantled by Upper Cretaceous marine and brackish-water sediments the area has obviously been raised by a lifting force, which acted to tilt the surface eastward in a long, very gentle monocline. The effect was general, devoid of local districts of more intense pressure, at least so far as surface indications might show. There are no normal faults of noteworthy extent in post-Carboniferous strata, but faulting and incidental folding of sedimentary beds occur in pre-Mississippian formations in a zone that ranges northeasterly from western Texas to eastern Kansas. In what follows the description relates to the pre-Mississippian structure, which is more obscure and apparently less concentrated than that which characterizes the Rocky Mountain province.

[11] G. K. Gilbert, "The Basin Range System, in Explorations and Surveys West of the Hundredth Meridian, Lt. Geo. M. Wheeler in Charge," Vol. III (1875), pp. 21–42, spec. p. 42.

In the Midland basin of West Texas the Permian lies in a gently warped attitude over disturbed older strata. An uplift of Ellenburger, Ordovician limestone, occurs as an isolated height, buried in Permian deposits that rest on its slopes. There is some faulting but its character is obscure and it has been interpreted as thrusting. This would not exclude the possibility of normal faulting as a primary structure, but none has been discovered and probably none is present in that area.

The much greater Ellenburger uplift of eastern Texas and Oklahoma has a geographic relation to the Llano upwarp, a positive continental element, which indicates that it is a northward extension of that feature. It also appears not be faulted, as is commonly the case with broad upwarps of that nature.

However, in the Llano area itself, where the pre-Cambrian has been raised nearly to the surface, normal faulting, producing complex graben-and-horst features, is strongly developed.

A major structure of eastern Kansas and Oklahoma is the Nemaha granite ridge. Although buried beneath Paleozoic strata, the drill has made its character evident. It is described by R. C. Moore[12] as being a very uneven ridge, 10 to 25 miles wide and 175 miles long. It varies in altitude from 600 feet above sea-level to at least 1,100 feet below that datum. The crest is uneven, it being deeply cut, either by erosion or by cross faulting. The rock is pre-Cambrian granite, which was raised above the general level of the basement rocks during Mississippian or early Pennsylvanian time. According to C. R. Thomas[13] there is no surface faulting, but subsurface faulting occurs east of the ridge. The eastern face is described as the eroded scarp of a normal fault, produced by the uplift of the western block rather than by the depression of the eastern side. It would appear that the structure is a single fault of the first magnitude, resulting from the lifting effect of vertical pressure, affecting an extensive area northwest of the shear, and in less degree or not at all active east of that line. The Pennsylvanian and Permian strata adjacent to the normal fault exhibit minor folding, which has been attributed to differential settling of shales over buried "anticlinal" hills. Thomas thought the cause inadequate and sought some contributory action; he did not recognize, however, that local compression and folding result from normal faulting. The well defined anticlines and synclines, developed along the Nemaha ridge are logical effects of that kind of deformation.

Proceeding in the survey of the United States to identify provinces characterized by normal-fault structures, we may consider the Central Lowland region of Illinois, Indiana, Kentucky, and Tennessee, as outlined on physiographic character by Fenneman.[14] By reference to the *Tectonic Map of the United States*,[15] we

[12] R. C. Moore, "Geologic History of Crystalline Rocks in Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 2 (1918), pp. 98–112.

[13] C. R. Thomas, "Flank Production of the Nemaha Mountains," *Structure of Typical American Oil Fields*, Vol. 1, Amer. Assoc. Petrol. Geol. (1929), pp. 60–72.

[14] N. M. Fenneman, "Physiographic Divisions of the United States," *Annals Assoc. Amer. Geographers*, Vol. VI (1930), pp. 19–98.

may identify within this area two types of structure, namely, very broad basins and upwarps, characteristic of the whole area, and clearly defined normal faults, which are accompanied by local folds in the stratified sedimentary beds. The upwarps are known as the Wisconsin, Kankakee, and Cincinnati arches, the Nashville dome, and the LaSalle anticline. They have been described as folds, but they differ from the typical folds of the Appalachian type in the extreme gentleness of the dips where they are covered by sediments and in the fact that they consist of crystalline rocks of the basement complex where the Paleozoic strata have been eroded. The complex can not be folded by horizontal compression; had it been subjected to the pressure that produced the Appalachian anticlines and synclines it must have been sheared into wedge blocks which would have been displaced both vertically and horizontally; and that structure must have appeared in the overlying strata, where they occur. The absence of the logical effects of compression nullifies the assumption of folding. On the other hand, the upwarps are of the kind characteristically developed in areas of the positive continental elements from which they extend. The upwarps and basins are expressions of differential veritcal forces according to any rational interpretation of the relations.

The normal faults express the same action; they are vertical shears, which cleave the basement complex and the overlying sediments and define masses that have been raised by a lifting force or depressed by gravity. The Ste. Genevieve normal fault, which bounds the Illinois basin on the southwest, is the vertical shear between the subsiding basin and the rising mass of the Missouri positive element. Lying *en échelon* with reference to the Ste. Genevieve fault is the Rough Creek normal fault, which likewise hades into the sunken area of the basin. Strata adjacent to the Rough Creek fault are described as intensely faulted and compressed and there is a gentle syncline about 6 miles south of the zone of faulting. The lateral pressure may be attributed to the forcible displacement of wedge-shaped sections by vertical uplift in opposition to gravity. Another area of intense normal faulting occurs south of the syncline at the head of the Mississippi embayment and appears to be related to that depression.

In the preceding pages the emphasis has been upon the action of a vertical lifting pressure, which acting against gravity produces normal faulting. The process and the resulting structures are described as in marked contrast to those of folding of the classic Appalachian type. It may here be reiterated that folding in the original meaning of the term can be produced only in bedded rocks. The basement complex can not fold. When compressed, it shears.

In the Appalachian structures, as in geosynclinal folds in general, we see only the folded strata. The basement complex is not exposed. Whether it shared in the shortening or not is a matter of inference. But there are areas in which the basement complex was not so deeply buried and did take part in the deformation. It there plays a major role. A brief description of two such provinces appears pertinent to the present purpose.

[15] Committee on Tectonics, National Research Council. Published by Amer. Assoc. Petrol. Geol. (1944).

WYOMING STRUCTURE

The name Wyoming is here proposed for that type of structure which is characteristically developed in Wyoming, especially in the Big Horn and Wind River basins, and adjacent areas. The dominant mountain-masses are the Big Horn, Wind River, and Beartooth blocks of pre-Cambrian granite and metamorphics. They stand high, with their bases buried in Mesozoic and Tertiary strata, which have accumulated to great depths over depressed segments of the basement complex. The region has been subjected to powerful horizontal compression from northeast to southwest. The stresses were sufficiently intense in the pre-Cambrian to shear it (it could not fold) and to displace the wedge-shaped blocks cut out by intersecting systems of shears. Wedges which pointed downwara were forced up and over; wedges which pointed upward were forced down and under. The former now stand as great mountain blocks; the latter are presumably buried in the basins, under the sediments, which have been washed in. Large vertical displacements have resulted from horizontal compression and great overthrusts have developed where a number of shearing planes coincided in alignment or massive blocks directed the resultant of the stresses. The strata have suffered notable folding.

This somewhat dogmatic assertion of the writer's[16] interpretation of the facts rests on mechanical principles of shearing as applied to inflexible masses and upon observation of the effect of compression in causing wedges to move in the direction of the resultant of stresses applied to their sides. It is illustrated in Figure 3, which presents part of a model deformed in this manner in 1887.[17]

The Wyoming area has for some years been the object of detailed study and interpretation by a committee of geologists from the universities of Chicago and Princeton. They appear to have reached agreement to the effect that the deformation has been dominated by pre-Cambrian structures, a conclusion with which the foregoing description is in agreement; but there is disagreement where folding of the complex is assumed, since the writer regards it as inflexible. The articles by R. T. Chamberlin[18] on wedge-block diastrophism and the control by the basement complex are most significant. Papers by his colleagues are cited in the articles referred to.

Elsewhere than in eastern Wyoming but in the Rocky Mountains, wedge blocks of folded sedimentary beds present a similar structure. The strata, folded in some previous orogenic activity, were rigid with reference to later compression and yielded by shearing into blocks, which were displaced vertically and laterally.

[16] B. Willis, "Mechanics of Appalachian Structure," *U. S. Geol. Survey Ann. Rept. 13* (1893), pp. 212–74.

[17] ———, Pls. XCIII and XCIV.

[18] R. T. Chamberlin, "The Wedge Theory of Diastrophism," *Jour. Geol.*, Vol. 33 (1925), pp. 755–92.
———, "Diastrophic Behaviour around the Big Horn Basin," *ibid.*, Vol. 48 (1940), pp. 673–716.
———, "Basement Control in Rocky Mountain Deformation," *Amer. Jour. Sci.*, Vol. 243-A (1945), Daly volume, pp. 98–116.

Blocks thus isolated have not only been raised, but may be thrust considerable distances from their original positions. It is doubtful that such mountain blocks as the pre-Cambrian masses of the Bighorns, Wind River, and Beartooth ranges are still in contact with their roots.

Wedge-block structure of the Wyoming type may be looked for in any part of the world where the basement complex or folded sedimentaries have been subjected to renewed orogenic pressure. The writer regards the isolated blocks of

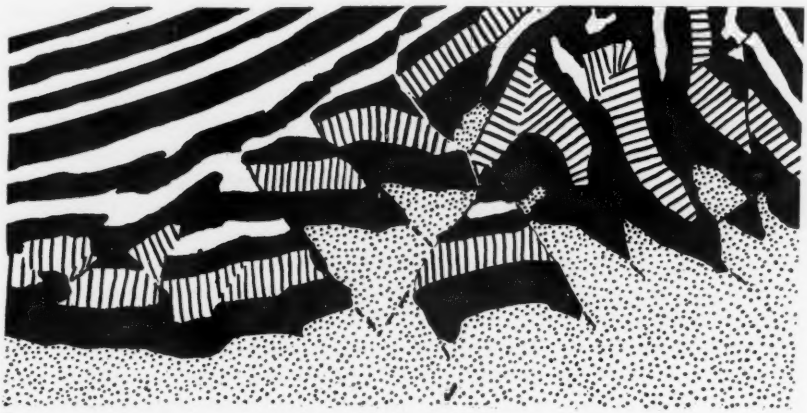


FIG. 3.—Wedge-block deformation in a model compressed from right to left in confined space under a load of 1000 pounds of shot. (See *Mechanics of Appalachian Structures*, Plate XCI.)

The triangular prisms are cut out by shearing planes caused by the pressure in homogeneous material, which under the conditions of load and stress, developed at approximately 45° to the applied pressure. The homogeneous material comprised 4 layers including the bottom one, dotted. They were all of the consistency of butter. Shearing was easier than folding because the layers could not slip on bedding planes. Note the vertical displacement of the wedges. It represents Rocky Mountain, Wyoming structures in granite, basal complex and folded Paleozoics. The strata in the upper left slipped on bedding planes and folded, as the Tertiary.

Jurassic limestone in the Alps, the Klippen, and even the great pyramid of the Matterhorn, as blocks of this character, sheared out of their original positions in folds of an earlier compression and forced up to levels far above once related masses. The current interpretation of Alpine structure simply as an effect of folding may be materially changed when the role of shearing is given its proper weight.[19]

CALIFORNIA STRUCTURE

The Coast ranges of California present a structure, not paralleled in the United States, which may aptly be called California. It is characterized by strike-slip faults of great length. They strike in general northwest and southeast and

[19] Albert Heim, *Geologie der Schweiz*, Band II (1922), p. 540 and Tafel XXV.

the nearly horizontal displacement is a movement of a southwestern mass northwestward past the adjacent mass on the northeast. The fault planes stand vertical and extend to great depths. On the principal one, the San Andreas rift, the earthquake focus of the 1906 shock was located at 25 miles below the surface.

The San Andreas is mapped as a continuous fault for 800 miles, but it comprises at least three distinct sections. A northern section extends from Cape Mendocino, Lat. 40°30′, to Lat. 35°, a distance of 450 miles. The central section trends strongly eastward around the Tehachapi Range and extends about 60 miles to a junction with the Garlock fault, which defines the Sierra Nevada. Thence the southern section continues about 300 miles to the Gulf of California.[20]

Each of these sections has a distinct earthquake record, peculiar to itself and not represented in the adjacent parts of the rift. Each of them is characterized by relations to minor structures, comprising complex shearing, folding, and thrusting. The details, which have been worked out in connection with the explorations of the oil fields and other economic as well as scientific investigations, are multifarious and the published accounts are voluminous. The purpose of this note is merely to emphasize the fact that in general the deformation of the basement complex in any district has controlled the deformation of the sedimentary beds overlying it and the shearing of the complex has been the dominant cause of the folding and minor faulting.

In the vicinity of San Francisco the intensely crushed strips that constitute the ridges are wedge-blocks that point downward and have consequently been forced up; while the bay of San Francisco and related valleys have developed in consequence of the depression of alternate strips. Similar ranges and valleys extending southward are the effects of similar structural developments and the physiographic and structural evidence demonstrates that the ranges and straits which have existed here since at least early Tertiary were due to the same structures.

The central section, the Tehachapi Range, is described by Buwalda[21] as a mass which has been uplifted with virtually no rotation, by faulting and warping along both its north and south margins. The direct uplift of such a mountain mass clearly indicates the action of compression against a block defined by convergent shears, which have cut a wedge from the basement complex. The mass is, however, so large that no simple wedge could have survived the crushing effects. The internal structure reflects the compression in complex faulting and folding.

The structure of the southern section of the San Andreas rift involves uplifts and depressions in very complex relations, which express the action of convergent pressures from northeast and southwest, combined with strike-slip shears that resemble those of the northern section in strike and relative displacements of the southwestern strip of any pair toward the northwest. The rocks affected are pre-

[20] *Atlas of the California State Earthquake Commission* (1910), map No. 1.

[21] J. P. Buwalda, "Structural Relation of the Tehachapi Mountains to the Sierra Nevada and Coast Ranges (abstract), *Geol. Soc. America, Cordilleran Section, Program* (1946), p. 8.

dominantly inflexible, granodiorite masses and metamorphics. They have been deformed by shearing rather than folding and the uplifts and depressions have obeyed the vertical components acting upon wedge-blocks defined by intersecting systems of shearing planes. In the development of the oil fields the emphasis is upon the folding of the Tertiary and Pleistocene sedimentaries, complicated by both thrusts and normal faults. The association of apparently contradictory stresses of compression and tension is evidence of the rotational strain imposed by displacements on the major strike-slip faults, which are developed in the basement complex.

SHEARING OR FOLDING

The object of this paper is to call attention to the very general development of shearing as a form of deformation of rock masses in the earth's crust, as a result of either vertical or horizontal compression, either alone or in combination with folding. The writer would emphasize the fact that even in simply folded, anticlinal and synclinal structure, shearing of the strata past one another on the bedding planes is an essential displacement, without which folding can not occur. Where there are no strata to slip or where strata are so locked by previous folding or other conditions that they can not slip, true folding is mechanically impossible. It is therefore misleading to use that term in connection with the earth's crust. Not only is the statement liable to be misunderstood. If it be used to describe as an anticline a strip which is bounded by normal faults the consequences may be economically unfortunate.

Shearing and folding very commonly occur in close association. Folding alone is found only in the simplest anticlinal and synclinal structures of bedded masses. Shearing is similarly characteristic of massive formations. And since orogenic pressures are commonly developed in the basement complex below any but the thickest deposits of sediments, shearing ordinarily controls.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 11 (NOVEMBER, 1946), PP. 1888-1898, 3 FIGS.

SPECTROCHEMICAL SAMPLE LOGGING OF LIMESTONES[1]

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ABSTRACT

Visual examination and insoluble-residue analysis have not yielded uniformly satisfactory data for detailed differentiation and correlation of thick and unbroken sequences of carbonate rocks. The method here presented is an attempt to utilize quantitative spectrographic analysis for this purpose.

An external standard method which gave results reproducible within inherent sample error was used. Ca, Mg, Sr, Ba, Al, Ti, Fe, and Si were present in all samples, and Mn and V in some. For practical reasons S, P, Na, and K, undoubtedly present, could not be determined. The most useful elements appear to be Mg, Fe, Al, and Sr. When analyses of both surface samples and well cuttings are plotted against stratigraphic interval or well depth, the curves may be interpreted in terms of stratigraphic correlation and differentiation.

Standardization of the method is easy and the results are not dependent on the personal equation. Apart from initial expenditure for equipment, costs and time-consumption should be less than those required for foraminiferal and insoluble-residue analysis.

INTRODUCTION

In many areas where carbonate rocks form important parts of the stratigraphic sequence, stratigraphers have experienced varying degrees of difficulty in differentiating and correlating limestones and dolomite units in both surface and subsurface work. Visual examination of samples under the binocular microscope is seldom satisfactory for the recognition of any but the major stratigraphic divisions; and, because of the lack of any standardization of the terminology applied to carbonate rocks, it is often nearly impossible for one worker to interpret a log prepared by another. The addition of tests for dolomite to routine microscopic sample study merely adds another qualitative measure, the sensitivity of which is subject to considerable influence by grain size and surface texture, while the recording of data varies with the vagaries of the human equation.

In certain areas, and with certain parts of the stratigraphic section, notably the early Paleozoic rocks of parts of the Mid-Continent province, insoluble residues yield a remarkable amount of stratigraphic data and correlations may be carried over broad distances. Elsewhere within the writers' experience, notably the Mississippian of Montana and Alberta, insoluble residue studies have not produced data which permit the splitting of thick carbonate sequences into small useful units; or if such units appear to be present in one set of samples they can not with any certainty be correlated with other sample suites. This failing is probably due in part to a low density of control points over much of the area, but this is not the whole answer. In most residues from Montana limestone of Meramec age, for instance, the chief constituents are chert, silt, and anhydrite,

[1] Read before the Association at Chicago, April 4, 1946. Manuscript received, May 27, 1946. Published with the permission of the director of the Montana Bureau of Mines and Geology.

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with nearly complete absence of quartz grains, accessory minerals, or other distinctive items. The chert is irregular in distribution and subject to sampling error. The amount of silt preserved in the residues depends on the amount decanted while washing; or, if it is all to be preserved, a tedious and time-consuming laboratory procedure must be followed. Anhydrite is unusable for surface to subsurface correlations, and in most cases, is as easily detected in the undigested sample.

Having encountered these difficulties, the writers wondered whether the most valuable and diagnostic part of the sample may not be thrown away with the spent acid. With this in mind, qualitative spectrochemical analyses of limestone samples were made seeking trace elements which might prove to be confined to a relatively limited stratigraphic range. Unfortunately, the results of this qualitative investigation were a triumph for the theory of uniformitarianism. All the limestones investigated appeared to be constituted of very nearly the same materials. Among the elements encountered in nearly all samples were calcium, magnesium, strontium, barium, aluminum, titanium, iron, and silicon, with, in some samples, manganese and vanadium. Sodium, potassium, sulphur, and phosphorus were undoubtedly present in most samples, but because of the technique followed these could not be recognized. It became obvious that any useful data must be gained through quantitative analysis. In the course of analysis of several thousands of samples the procedure explained later in this paper was developed.

Quantitative analyses of both surface and subsurface samples, including cuttings and cores, indicate that the most useful elements are magnesium, iron, strontium, and aluminum, these elements being present in measurable quantities in practically all samples. When the results of these analyses are plotted against well depth or stratigraphic interval the resulting curves or histograms make possible the differentiation of large carbonate sequences into small recognizable units, and these units may be correlated from well to well or from surface section to subsurface.

ESSENTIALS OF SPECTROCHEMICAL METHOD EMPLOYED

Most of the satisfactory methods used in quantitative spectrum analysis are applicable to conducting metals only, for the metals form the electrodes in the arc or the spark-gap. Quantitative analysis of non-conducting minerals or of loose aggregations such as mineral powders presents its own problems, the only satisfactory solution consisting of placing the sample in a cavity drilled in a conducting electrode, usually graphite. Following a survey of spectrochemical methods proposed for mineral analysis, and taking into account the limitations of the available equipment, the writers adopted Slavin's "total-energy method"[4] for this investigation.

[4] M. Slavin, "Quantitative Analysis Based on Spectral Energy," *Indus. and Eng. Chemistry*, Analytical Edition, Vol. 10 (1938), pp. 406–11.

———, "Iron Arc as a Standard Source for Spectrochemical Analysis," *ibid.*, Vol. 12 (1940), pp. 131–33.

The basis of quantitative spectrochemical analysis[5] is that the greater the quantity of an element in an excitation source (flame, arc, or spark) the greater is the intensity and hence energy of a given spectrum line emitted by that element, provided that all variable factors such as spectrograph slit-width, optical arrangement, arc gap, and excitation conditions remain constant. These last-mentioned conditions are mechanical or electrical, and reasonable constancy may be assumed.

If the energy emitted by a spectrum line of an element could be measured directly, correlation of quantity with energy could be effected, and analysis by this method should become simple. Until recently, there has been no success in this direction, but within the last few years direct intensity measurement of spectrum lines has been attained.[6]

In the absence of such convenient methods, the photographic emulsion is used to integrate the light energy contained in the spectrum lines, for there is direct correlation between the energy (or intensity) and the photographic blackening, or "density of blackening," produced in the emulsion. The density of blackening is usually measured on a densitometer or microphotometer. Plotting of density of blackening against the logarithm of the corresponding light energy gives what is known as a "characteristic curve" of the photographic emulsion. This is shown in Figure 1 where the intensity of the 5183.6 Å line of magnesium is plotted against the corresponding optical density of the line on the spectrograms. Six points are plotted, representing six spectrograms; these were obtained by weighing out six 5-milligram samples of a standard[7] lime-magnesia carbonate containing 11.83 per cent MgO and completely volatilizing them in an arc under reproducible and constant conditions. Line intensity was varied by using a rotating sector in front of the spectrograph slit, the least amount of light being admitted when the sector aperture scale read 5, the most when the scale read 100. As the amount of light admitted is proportional to the scale reading, the amount of energy falling on the photographic emulsion is proportional to the sector opening,

[5] "Spectrochemical analysis" is a contraction for "spectrographic chemical analysis." As used in this paper, the term refers to chemical analyses utilizing the spectrograph as an analytical tool.

[6] D. H. Rank, R. J. Pfister, and P. D. Coleman, "Photoelectric Detection and Intensity Measurement in Raman Spectra," *Jour. Optical Soc. of America*, Vol. 32, No. 7 (July, 1942), pp. 390–96.
M. F. Hasler and H. W. Dietert, "Direct Reading Instrument for Spectrochemical Analysis," *ibid.*, Vol. 34, No. 12 (December, 1944), pp. 751–58.
G. H. Dieke and H. M. Crosswhite, "Direct Intensity Measurements of Spectrum Lines with Photo-Multiplier Tubes," *ibid.*, Vol. 35, No. 7 (July, 1945), pp. 471–80.
George A. Nahstoll and F. R. Bryan, "An Application of Multiplier Photo-Tubes to the Spectrochemical Analysis of Magnesium Alloy," *ibid.*, Vol. 35, No. 10 (October, 1945), pp. 646–50.

[7] Initially, synthetic standards were used but these were unsatisfactory due to improper burning characteristics and lack of uniform mixing. The most satisfactory standards were prepared by mixing, in equal proportions, U. S. Bureau of Standards standard samples No. 1a (argillaceous limestone) and No. 88 (dolomite), resulting in a mixture with the following percentages of relevant elements.

	Percentage		*Percentage*
SiO_2	7.21	MgO	11.83
Al_2O_3	2.12	CaO	35.90
Fe_2O_3	0.86	SrO	0.06

and consequently sector openings (on a logarithmic scale) can be plotted directly against optical density.

By Slavin's total-energy method, this curve may be used to determine the magnesia content of any other sample the spectrogram of which has been photographed on the same film or photographic plate. Thus, if a 5-mg. sample of a

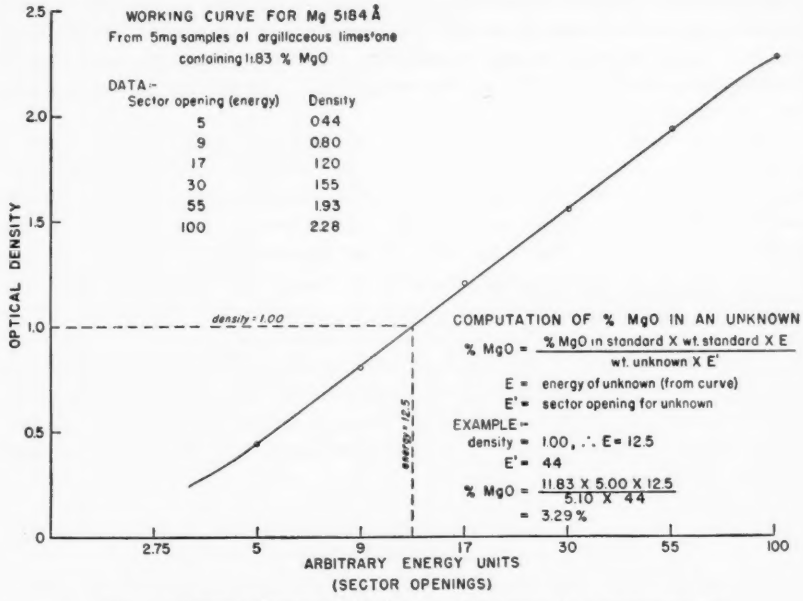

FIG. 1.—Example showing utilization of working curve for a magnesium line.

limestone were volatilized under the same arc conditions as the standard samples, with a sector opening of 44, and the measured optical density of the 5183.6 magnesium line were 1.0, then *the arbitrary energy content of the line*, by interpolation from the curve, is seen to be 12.5. On the basic assumption that the line intensity (or energy content) is proportional to the amount of the element, then from the example given the amount of magnesia in the limestone is:

$$12.5/44 \text{ times } 11.83\%, \text{ or } 3.36\% \text{ MgO}.$$

It is inconvenient to weigh a large number of samples to any given weight, although large variations from the weight of standard taken should not be tolerated. In the present investigation all samples other than the standards were weighed to within 0.20 mg. of 5 milligrams, and the exact weight of each sample was recorded. Again, as the line intensity is proportional to the mass of the element present, all other conditions being constant, correction for weight of

sample is simple. Thus, in the example given, had the weight of sample been 5.10 milligrams, then the magnesia content would have been:

5.00/5.10 times 3.36, or 3.29% MgO.

The method outlined is simple, but does not give the highest accuracy. As the problem under investigation was considered to be exploratory in nature, high accuracy was not considered essential. No correction was made for "background density," and although Strock[8] states that in at least one case more normal results are obtained by neglecting the background, it seems best to apply a correction as given by Twyman,[9] or Brode.[10]

Another possible source of error is the effect of extraneous elements on the intensities of the lines of the elements being investigated. This matter has been discussed by Brode,[11] who points out that substantial amounts of elements of low ionization potential tend to diminish the line intensities of elements of higher ionization potential. Slavin,[12] however, states that he had no difficulty in this respect, and some preliminary experiments by Cooke seem to indicate that there is no direct correlation between the ionization potential of a large amount of an extraneous element and the line intensity of an impurity element of higher ionization potential, when the "total energy" method is used. Indeed, with the limestones and dolomites investigated, this effect should not materially vitiate the results, for the ionization potentials of calcium and magnesium are not greatly different. If the effect is a real one, it should be more noticeable with argillaceous and siliceous limestones and dolomites.

APPARATUS AND TECHNIQUE EMPLOYED

SPECTROGRAPHIC EQUIPMENT

The spectrograph used in the investigation is a 5-foot Wadsworth type grating spectrograph[13] with an original first-order concave grating. The arc stand is standard Bausch and Lomb equipment, provided with a quartz condensing lens for imaging the arc on either the spectrograph slit or on the collimating mirror. An additional lens serves to project an image of the electrodes and arc on the laboratory wall, permitting close control of gap and arc alignment during exposures.

[8] Lester W. Strock, *Spectrum Analysis with the Carbon Arc Cathode Layer*, pp. 39–41. Adam Hilger, Ltd., London (1936).

[9] F. Twyman, *The Spectrochemical Analysis of Metals and Alloys*, pp. 98–99. Chemical Publishing Company, Inc., Brooklyn, N. Y.

[10] Wallace R. Brode, *Chemical Spectroscopy*, p. 95. John Wiley and Sons, Inc., New York (1939).

[11] *Ibid.*, pp. 98–102.

[12] M. Slavin, "Quantitative Analysis Based on Spectral Energy," *Indus. and Eng. Chemistry*, Vol. 10 (1938), p. 410.

[13] Robert A. Wilson, *The Design and Construction of a Five-Foot Wadsworth Type Grating Spectrograph*. A thesis submitted to the Department of Mineral Dressing in partial fullfilment of the requirements for the degree of M.S. in mineral dressing. Montana School of Mines, Butte, Montana, June, 1941.

The spectrograph was designed to cover the spectrum from 2,000 to 10,000 Ångstrom units, any one setting covering approximately 2,500 Ångstrom units. Linear dispersion varies slightly with the wave-length region being photographed, but is always very close to 10.8 Å per millimeter.

Arc excitation is furnished by a motor-generator which delivers direct current at 150 volts through a variable ballast resistor. This, with a variable field resistor, permits accurate control of the impressed voltage to the arc. It is realized that higher arc currents could have been carried, giving shorter exposures, if 220-volt direct-current had been used, but unfortunately the necessary apparatus was not available.

PREPARATION OF SAMPLES

Where surface samples were involved, these were collected as representative chips from each 10 feet of accurately measured stratigraphic interval. Under certain conditions closer intervals may be required, but the writers have found this distance to be satisfactory for most cases. Samples were crushed with a maul on an easily cleaned iron plate and then were screened in running water, the minus two-mesh, plus eight-mesh material being retained. After drying, representative fragments of the sample were selected for analysis. Fragments containing chert were rejected, as were those with weathered surfaces. The selected material, after further grinding in a porcelain mortar, and final reduction to a powder in an agate mortar, was placed in a labelled glass vial and was ready for analysis.

Subsurface samples, resulting from continuous coring, were handled in a similar manner, whereas carefully picked and washed cuttings went direct to the final grinding and powdering.

SAMPLE WEIGHING AND ELECTRODE LOADING

All standard samples used in obtaining the calibration curves weighed 5 milligrams, plus or minus 0.01 milligram. All other samples, as previously mentioned, were weighed to the nearest 0.01 milligram within 0.2 milligram of 5 milligrams, and their weights recorded. All samples were weighed on a Roller-Smith torsion balance[14] weighing to 25 milligrams, this type of balance possessing the three advantages of reproducibility, accuracy when calibrated, and rapidity of operation.

Initially, all samples were weighed out in duplicate and analyzed spectrochemically, but the accordance between duplicates was so good that this practice was discontinued. Single samples are satisfactory, no doubt, for an exploratory program, but it would be preferable to run duplicate samples in routine logging.

The weighed samples were transferred from the balance pan to a small launder made of assay silver, thence through a small, easily cleaned glass funnel

[14] Roller-Smith Company, Bethlehem, Pennsylvania.

to the electrode. Platinum is a more suitable material for the launder than silver.

All electrodes were bored and shaped from $\frac{1}{4}$-inch Atcheson graphite spectrographic "carbons." These contained so little of the elements being investigated that the additional cost of purification, or of purchase of specially purified graphite electrodes was considered unnecessary.

Some trouble was experienced by the shape initially adopted for the electrodes. After striking the arc the samples heated rapidly, and in a few seconds were above the dissociation temperature of the carbonates. The resulting rapid gas evolution blew portions of the powdered sample from the electrode. This problem was solved by an electrode shaped as shown in Figure 2. The central hole, which carries the sample, was first bored to depth, the electrode being carried in a chuck not unlike that of a small drill-press. The final shaping was effected

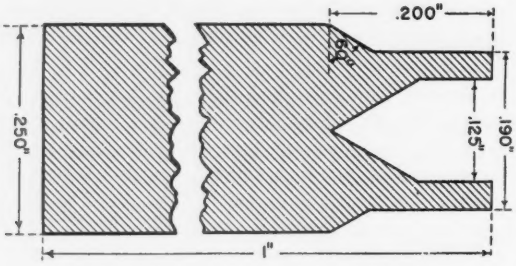

FIG. 2.—Diagram showing shape of electrode.

by running a specially shaped tool over the end of the electrode. The method is rather cumbersome, and an automatic machine could doubtless be devised to accomplish the same result with much less expenditure of labor.

With a 5-milligram sample and at 150 volts these electrodes burn very well, with no indication of sample "blowing." The thin-walled graphite cylinder burns sufficiently slowly to permit a slow and orderly decarbonization of the carbonates, so that by the time the gas column of the arc reaches the sample, it has been converted to oxides. With an arc gap of approximately 5 mm., the current remains at 8 amperes for 55 to 60 seconds. During this interval the spectrum is that of the graphite, that is, carbon and cyanogen bands. At the end of this period the current abruptly jumps to approximately 15 amps. as the solids commence to volatilize. Complete volatilization of 5-milligram calcium and magnesium carbonate samples may take from 60 to 65 seconds under the conditions stated, but is ordinarily complete in 50 seconds.

The initial burning away of the graphite cylinder unfortunately contributes to fog and background on the spectrogram, but the advantages gained by even burning of the samples more than compensate for this disadvantage.

PHOTOGRAPHIC PROCESSING

The spectrograph used in this investigation was designed to use 35-mm. film, which limited to twelve the number of spectrograms which could be made on any one film. Where many samples required analysis, the number of film-strips requiring processing grew to embarrassing proportions, increasing the difficulties of adequate development. Undoubtedly, a large Littrow quartz spectrograph would shorten the time required per sample by permitting a larger number of spectrograms to be photographed on one large plate. Further, brush development, recommended to eliminate the Eberhardt effect, is certainly easier to use on plates than on films. Reciprocity error can be reduced to a minimum by proper choice of photographic emulsion. Standard developers and fixers were used in the investigation, and all films were developed under carefully controlled temperature conditions to a gamma of approximately unity.

DENSITY MEASUREMENTS OF SPECTRUM LINES

Line densities on the processed films were measured on a Gaertner spectrum microdensitometer.[15] This is a subjective type instrument, requiring a widened line for measurement, with a corresponding loss in resolution and an increase in fogging and background density on the plate or film. With this densitometer minimum line widths were 0.1 mm., or at the linear dispersion employed, approximately 1.1 Ångstrom units. Under these circumstances impurity lines had to be chosen which were well separated from other lines which might be partly or completely superimposed on the line under measurement.

Unquestionably, the analytical work could be greatly speeded up, and less eyestrain induced in the worker, by using a photoelectric microphotometer, of which a number of types are available.[16]

COSTS

During the course of experimental work on this problem costs per sample analyzed have averaged 30 cents. This figure includes laboratory labor at one dollar per hour for sample and electrode preparation, burning of the sample, development, density measurement, and calculation of percentages of four elements. The figure also includes expended material such as electrodes, film, and photographic chemicals. Undoubtedly, under routine conditions of analysis of large numbers of samples the costs per sample for grinding, a large factor in total cost, could be considerably reduced.

Where such equipment is not available, an original capital expenditure of

[15] S. Jacobsohn and W. H. Kliever, "A New Microdensitometer Based on That of Hartmann," *Jour. Optical Soc. America*, Vol. 25 (August, 1935), pp. 244–45.

[16] Harry W. Dietert Company, 9930 Roselawn Avenue, Detroit, Michigan.
Adam Hilger, Ltd. 98 Kings Road, Camden Road, London, N.W. 1, England.
General Electric Company, Schenectady, New York.

about $4000 would be required to set up a laboratory for spectrochemical analysis. This figure includes an appropriate spectrograph, excitation equipment, densitometer, source of adequate D. C. power, and equipment for the shaping of graphite electrodes.

INTERPRETATION OF RESULTS

Figure 3 illustrates the results of a typical series of analyses. There are represented two surface sections and one well, involving Mississippian limestones and dolomites in an area of complex structure in northwestern Montana. In this area pre-Jurassic erosion has cut to varying and difficultly determined depths in the Mississippian. Neither binocular examination of samples nor insoluble residue analysis has successfully delineated zones which may be used as markers in the Mississippian of this area. The plotting of spectrochemical data, however, makes possible the recognition of zones which are indicated by dashed lines on the diagram. The upper of these is characterized by high iron content and low magnesium. Immediately below is a zone of high aluminium content, grading downward into a high magnesium zone. At about 990 feet in The California Company's well a zone is entered which is characterized by decreasing magnesium and increasing strontium; similar zones may be recognized in the two surface sections. Below this zone both the Cabin Creek surface section and The California Company's well encounter a zone of markedly decreased magnesium, followed by a zone very high in strontium percentage. Sampling in the third section was not carried low enough to enter this zone.

Admittedly, the example illustrated does not present spectacularly clear data for correlation, but it should be recognized that the sediments involved were formed under extremely stable conditions without any change in the environment of deposition or major variation in the material deposited. Moreover, the three sections are on three separate thrust blocks and their original positions undoubtedly represented a vastly greater geographic separation than that indicated by the present locations.

Samples resulting from continuous coring of the Paleozoic section in the State Royalty Petroleum Company's State well No. 1 (Sec. 35, T. 4 N., R. 1 E., Harding County, South Dakota) provided an opportunity to apply the spectrochemical method to a sequence of varied lithologies broken by disconformities. Although at the time these samples were run, the technique of analysis had not reached a satisfactory stage of development, the plotted analyses clearly delineated the major stratigraphic breaks and indicated the positions of several potential marker horizons in the thick sequences of Mississippian and Ordovician carbonates and evaporites.

Analysis of other sample suites involving thick anhydrite sections indicates that the presence of evaporites does not offer any difficulties. In fact, there is evidence to indicate that correlation between sections bearing evaporites, and those from which such material has been leached, or in which it was never deposited, may be accomplished.

CABIN CREEK
25-23N-10W

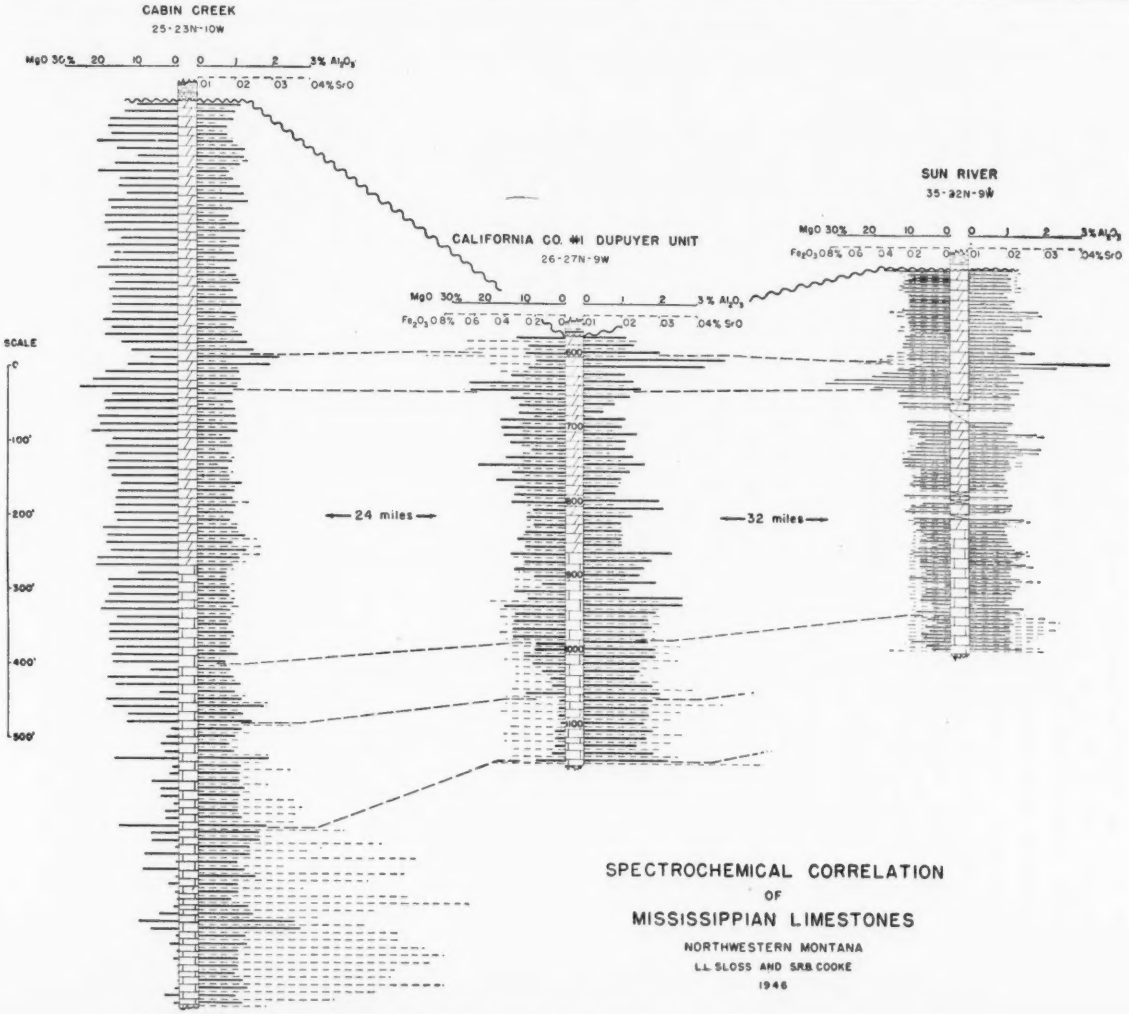

FIG. 3.—Spectrochemical correlation of three Mississippian limestone sections from northwestern Montana.

It is clear from the work done to date that it is far more important to plot the relative differences in the percentages of the various elements through a fairly thick sequence, than it is to determine the absolute percentages in any single sample or small group of samples. It may be possible in some areas and with some parts of the stratigraphic section to identify and correlate units on the basis of a few scattered samples, but in the writers' investigation it has been found necessary to use closely spaced samples, collected over fairly long stratigraphic intervals.

CONCLUSIONS

The preliminary work done thus far indicates that the spectrochemical method offers a possibility of solution for some heretofore insoluble problems of correlation. However, much work remains to be done before the method will be applicable over wide areas. It is probable that the four elements which have been proved useful in the investigation reported here will not be useful elsewhere and that other elements must be substituted. Magnesium, for instance, has been a most useful element for correlation in the Paleozoic section of the northern Rockies and adjacent Great Plains, but it would be of very doubtful value in areas of local dolomitization. Moreover, standards which the writers have used for purposes of comparison with unknown samples will undoubtedly need to be revised in other areas and in other parts of the section. Future investigations should also include attempts to apply the method to other sediments than the chemical and organic precipitates to which the present writers' work has largely been confined.

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VOL. 30, NO. 11 (NOVEMBER, 1946), PP. 1899-1909, 3 FIGS.

FAULTING IN EAST PART OF GRAND CANYON OF ARIZONA[1]

C. E. VAN GUNDY[2]
Altadena, California

ABSTRACT

The characteristics of several faults and their associated folds in the Grand Canyon district of Arizona are clearly shown by the excellent exposures of the rocks in the deeply dissected canyons of this region. Two of the major faults in this region have been active in the pre-Cambrian and again in post-Paleozoic time. These faults show at least two periods of movement and a reversal in the direction of movement of the thrown side. Monoclines, anticlines and synclines appear to have been formed by the combination of normal faulting at depth and the regional dip.

INTRODUCTION

The characteristics of several faults and their associated folds in the Grand Canyon district of Arizona were studied by the writer in 1933 and 1934 while mapping the geology of the Bright Angel and Vishnu quadrangles. In this region the complexities of the movements along several of the faults are clearly shown by the excellent exposures of the rocks and the deeply dissected canyons afford an opportunity to observe the results of movements which have taken place through an extremely long period of geological time as well as the effects of the movements of normal faults at depths and the variation in movement along the faults. Inasmuch as several surface and subsurface structures in other areas, particularly in California, which have been brought to the attention of the writer, suggest that the structural control may be analogous to that found in the Grand Canyon region, a summary of the results of the Grand Canyon study is presented herein with the belief that perhaps a description of some of these structures may serve as an aid in the interpretation of some of the faults and folds which have developed under similar conditions but in areas where the exposures are obscure or the data are meager.

REGIONAL STRUCTURE AND STRATIGRAPHY

The Grand Canyon is located in northern Arizona on the Colorado Plateau. That part of the Colorado Plateau which is located in the Grand Canyon district, north of the Colorado River, is composed of five minor plateaus or platforms, each of which is bordered by a north-south-trending fault or fold. The elevations of these platforms vary from 6,000 feet in the westernmost Shivwits Plateau to 8,500 feet on the Kaibab Plateau. The easternmost plateau, which is immediately east of the Kaibab Plateau, is known as the Marble Platform and has

[1] Manuscript received, November 25, 1944; revised copy received, June 1, 1946.

[2] 2350 Catherine Road. It is a pleasure to acknowledge the assistance of E. C. Doell and R. A. Bramkamp in the field and of members of the faculty of the University of California Geological Department for council during the Grand Canyon investigation. The writer is indebted to the Carnegie Institution of Washington for contributing financial support in the field, to J. C. Merriam who initiated the study of the Grand Canyon, and to N. E. A. Hinds who conducted geological studies in this region. The National Park Service and particularly E. D. McKee extended numerous courtesies.

It is clear from the work done to date that it is far more important to plot the relative differences in the percentages of the various elements through a fairly thick sequence, than it is to determine the absolute percentages in any single sample or small group of samples. It may be possible in some areas and with some parts of the stratigraphic section to identify and correlate units on the basis of a few scattered samples, but in the writers' investigation it has been found necessary to use closely spaced samples, collected over fairly long stratigraphic intervals.

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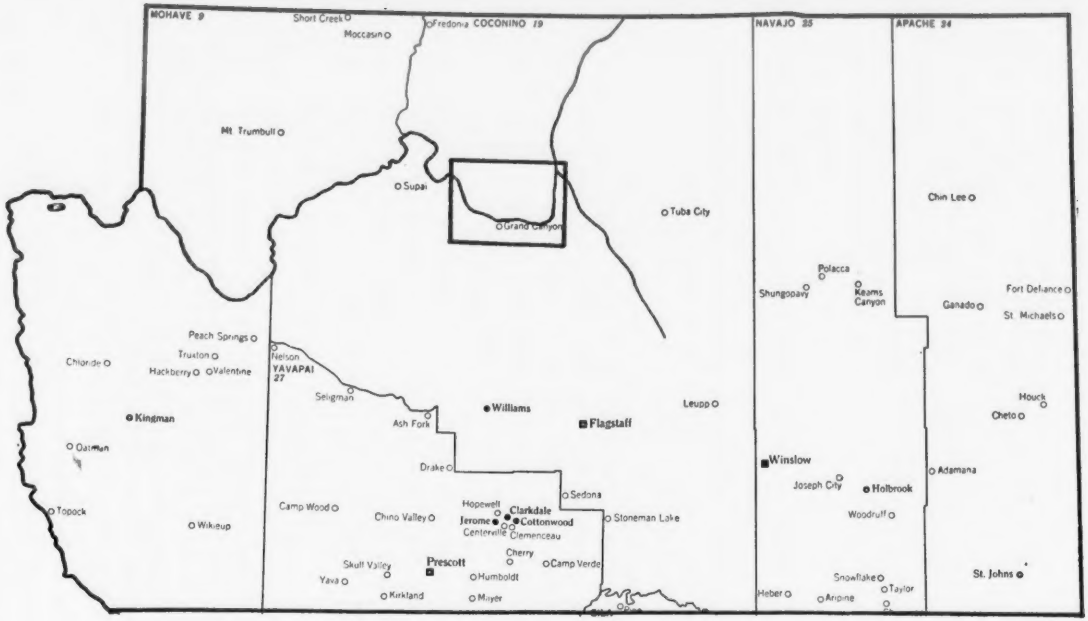


FIG. 1.—Index map of northern Arizona showing location of area discussed.

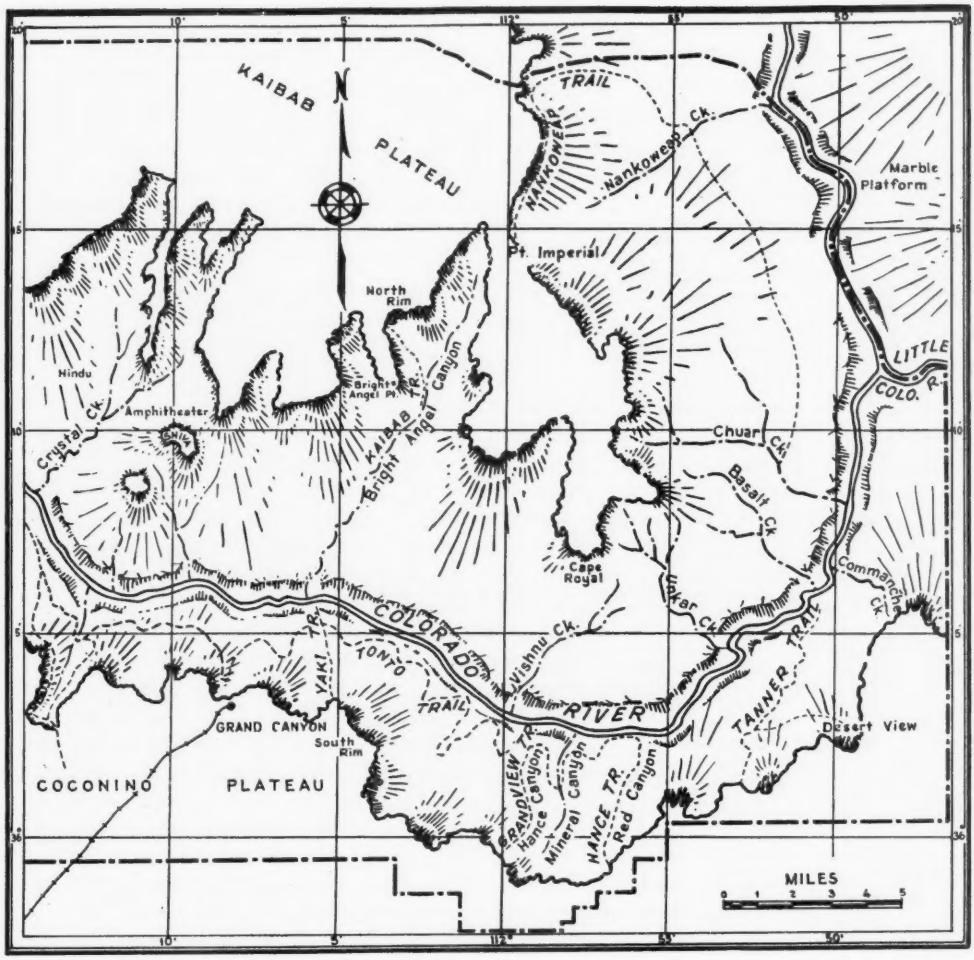


FIG. 2

an elevation of approximately 6,500 feet. The Grand Canyon, which has been carved into these plateaus and platforms, is approximately 200 miles long, 20 miles wide, and 1 mile deep in the area discussed in this paper.

The stratigraphic section exposed in the Grand Canyon includes Archean schists, gneisses, and granitic rocks; pre-Cambrian, Paleozoic, and Mesozoic sediments; and Recent terrace gravels. Strata of Mesozoic and Tertiary age are

practically absent in the Grand Canyon proper but good sections of these rocks are exposed a few miles north. The pre-Cambrian and Paleozoic stratigraphy is summarized as follows.

		Thickness in Feet
MESOZOIC ERA		
Triassic period		
Moenkopi formation		
PALEOZOIC ERA		
Permian period		
Kaibab formation		600– 800
Toroweap formation		200– 290
Coconino sandstone		400– 500
Hermit shale		300±
Supai formation		900–1,200
Mississippian-Pennsylvanian period		
Redwall limestone		500– 600
Devonian period		
Temple Butte limestone		100±
Cambrian period		
Tonto group		1,200±
Muav limestone		
Bright Angel shale		
Tapeats sandstone		
ALGONKIAN SYSTEM		
Chuar group		5,100–5,300
Nankoweap group		330
Unkar group		6,800–7,200
Basalt flows and interbedded sediments	(1,090)	
Dox sandstone	(3,071)	
Fourth member (147)		
Third member (735)		
Second member (687)		
First member (1,502)		
Shinumo sandstone	(1,200)	
Hakatai shale	(500)	
Bass limestone	(200)	
Total		17,790
ARCHEAN SYSTEM		

FAULTING

The Paleozoic rocks in the Grand Canyon region have a general southwestward regional dip which is interrupted by folds and normal faults. Two of these faults are described herein, namely, the Bright Angel fault and the Butte or East Kaibab fault. The Bright Angel fault, shown on Figure 3, extends from Grand Canyon Village on the south rim of the Grand Canyon to the Colorado River and northward along Bright Angel Canyon almost to the north rim of the Grand Canyon. The Butte fault is located at the extreme eastern part of the Grand Canyon and separates the Kaibab Plateau from the Marble Platform. These faults show evidence of a complex history with displacement in both pre-Cambrian[3] and post-Paleozoic time. Both of these faults show a reversal of the

[3] The term pre-Cambrian, as used herein with reference to faulting, designates displacement dated as post-Unkar group and pre-Tapeats sandstone (lower or middle Cambrian); it is probably post-Chuar group.

thrown side and terminate in branch faults and folds, a feature which has been noted by Walcott.[4] The several faults and folds which have displaced the Redwall limestone are indicated on the structural contour map (Fig. 3), the datum for which is the top of that formation. The top of the Redwall limestone has been selected for structural contours because it is well exposed and is representative for the entire Paleozoic sequence in this area since the angular discordance between the Paleozoic formations is negligible.

Bright Angel fault.—The displacements along the Bright Angel fault are summarized as follows.

Direction of Movement	*Magnitude of Movement*	*Date of Movement*
1. Downthrown on west	600± feet	Pre-Cambrian
2. Downthrown on east	180± feet	Post-Paleozoic

The first period of movement is well shown in at least three places. 1. On the south side of the Colorado River where remnants of the Bass limestone are exposed on the western side of the fault. Here, the entire Unkar group has been removed by erosion on the eastern side of the fault and the Tapeats sandstone rests directly on the Vishnu schists. 2. On the north side of the Colorado River, near the mouth of Bright Angel Canyon, where 1,500 feet of Unkar sediments are exposed below the Tapeats sandstone on the western side of the fault and the Tapeats sandstone rests directly on the Vishnu schists on the eastern side of the fault. 3. Toward the north end of Bright Angel Canyon where the Bass limestone-Vishnu schist contact is offset, a throw of 500 to 600 feet downthrown on the western side is indicated. The post-Paleozoic movement is well shown on the south wall of the Grand Canyon where the Coconino sandstone has been downthrown 180 feet on the eastern side. The Bright Angel fault passes upward into a monoclinal fold at both the south and north rims of the Grand Canyon. The lower side of the monocline is on the east. The monocline is believed to have been caused by the faulting and evidence supporting this conclusion is presented in the discussion on folds.

Butte fault.—The Butte fault can be traced for 15½ miles in the Grand Canyon. Monoclinal folds extend for several miles on the surface of the plateau from each end of the fault and apparently represent the same line of displacement. The displacements along the Butte fault are summarized as follows.

Direction of Movement	*Magnitude of Movement*	*Date of Movement*
1. Downthrown on west	600+ to 1,400± feet	Pre-Cambrian
2. Downthrown on east	300 to 2,700± feet	Post-Paleozoic

The pre-Cambrian displacement which was downthrown on the western side is shown clearly at the northern end, along the central part of the fault, and

[4] C. D. Walcott, "A Study of a Line of Displacement in the Grand Canyon of the Colorado," *Bull. Geol. Soc. America*, Vol. 1 (1890), pp. 49–64.
F. L. Ransome, "Pre-Cambrian Sediments and Faults in the Grand Canyon of the Colorado," *Science*, Vol. XXVII, No. 695 (1908).
E. D. McKee, "The Origin of Bright Angel Canyon," *Grand Canyon Nature Notes*, Vol. 6, No. 2 (1931).

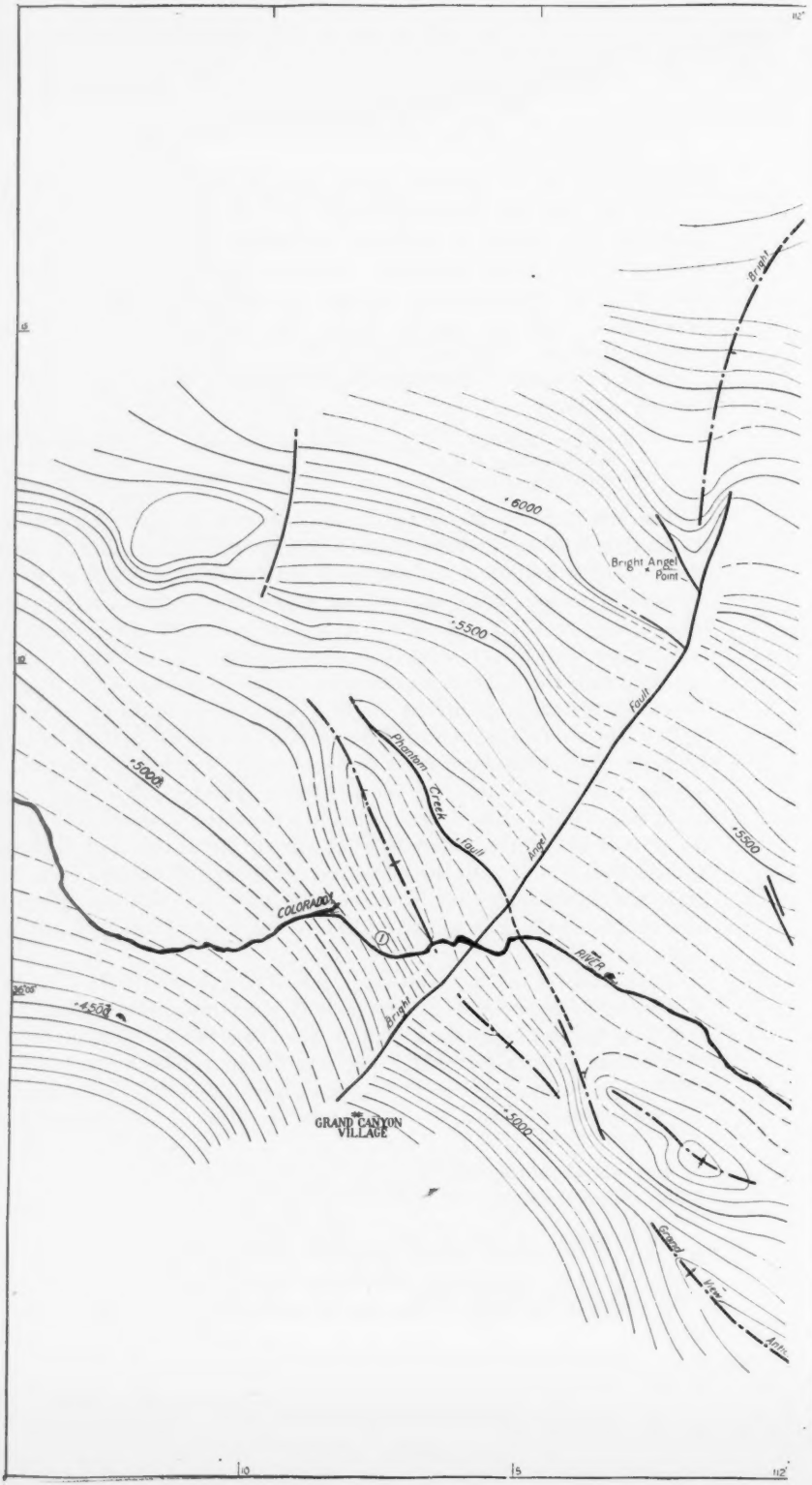
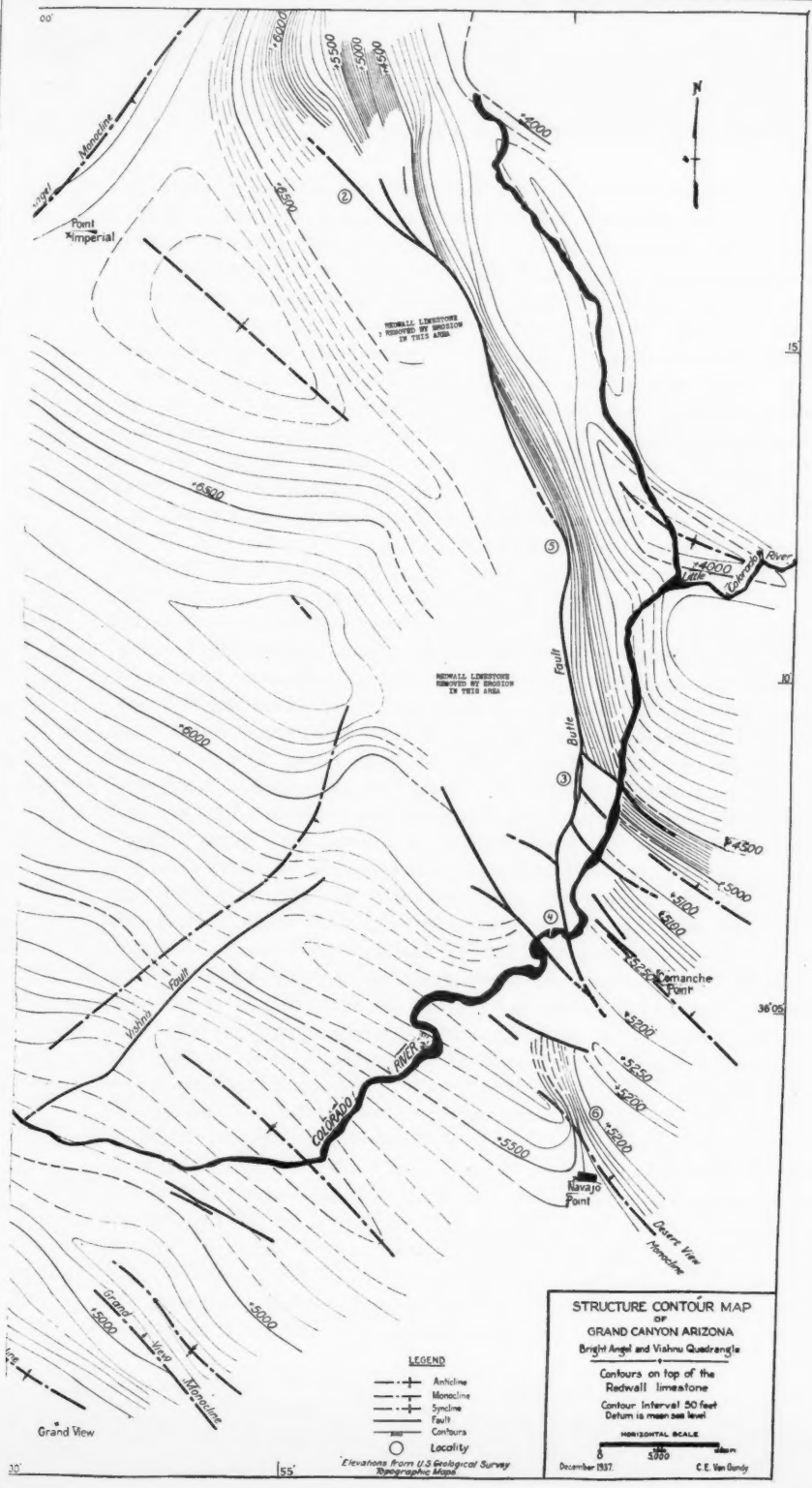

6000
5500
5000
4500
Bright Angel Point
Phantom Creek fault
Bright Angel fault
COLORADO RIVER
GRAND CANYON VILLAGE
112°
36°05'

FIG. 3


00'
Point Imperial
Monocline
-6000
-5500
-5000
-4500
-4000
-6500
-6500
-8500
-6000
-5000
-5000
-5500
REDWALL LIMESTONE REMOVED BY EROSION IN THIS AREA
REDWALL LIMESTONE REMOVED BY EROSION IN THIS AREA
Butte Fault
Little Colorado River
-4500
-5000
-5100
-5100
-5250
-5200
-5250
-5200
-5200
-5500
Comanche Point
Navajo Point
Vishnu Fault
COLORADO RIVER
Desert View Monocline
Grand View Monocline
Grand View
15
10
36°05
30'
55'
N
LEGEND
Anticline
Monocline
Syncline
Fault
Contours
Locality
Elevations from U.S. Geological Survey Topographic Maps
STRUCTURE CONTOUR MAP
OF
GRAND CANYON ARIZONA
Bright Angel and Vishnu Quadrangle
Contours on top of the Redwall limestone
Contour Interval 50 feet
Datum is mean sea level
HORIZONTAL SCALE
0
1000
December 1937
C.E. Van Gundy

at the southern end of the Butte fault. At Nankoweap Creek (Fig. 3, locality 2) the basalts are in fault contact with sediments of the Chuar group which occur on the western side of the fault. Although an accurate measurement of the ammount of displacement in this area could not be made, it was more than 575 feet because 375+ feet of basalt and 200± feet of Nankoweap sediments are exposed below the Chuar group in this area. Approximately 4 miles south of the Little Colorado River at locality 3 (Fig. 3), the pre-Cambrian displacement was more than 1,500 feet because the lower part of the basalts are in fault contact with sediments which occur 300 to 400 feet above the base of the Chuar group. The thickness of the basalt series and the Nankoweap group is more than 1,100 feet. Toward the southern end of the Butte fault, at locality 4 on the Colorado River, the basalts are in fault contact with the second member of the Dox sandstone. This indicates that the basalts have been downthrown 1,400+ feet on the western side in pre-Cambrian time.

The post-Paleozoic movement in general follows the zone of pre-Cambrian displacement. Along the northern part of the Butte fault, the post-Paleozoic movement was greater than the pre-Cambrian movement whereas along the southern part of the fault, the pre-Cambrian movement was greater than the post-Paleozoic movement. Along the southern part of this fault, most of the post-Paleozoic movement has taken place along the several branch faults so that the displacement along the line of the pre-Cambrian Butte fault is less than farther north where the entire displacement took place along a single zone of fracturing. At Nankoweap Creek (locality 2, Fig. 3), the combined movement represented by faulting and drag folds is 2,700± feet as indicated by the displacement of the Redwall limestone approximately one mile south of Nankoweap Creek. At locality 5 (Fig. 3), the strata of the Supai formation are in fault contact with those of the Chuar group, therefore a post-Paleozoic displacement of approximately 2,500 feet, downthrown on the eastern side has taken place at this locality. This relationship is shown in Figure 5. The first main branch of the post-Paleozoic Butte fault occurs approximately 4 miles south of the Little Colorado River. Here, the beds of the Nankoweap group are in fault contact with the base of the basalts and the strata are displaced downward on the northeastern side. The Cambrian Tapeats sandstone has suffered a displacement of 700± feet which is represented by faulting and drag folds. The movement is also shown by a monoclinal fold in the Redwall limestone where beds on the northeastern side of the fold are 600 feet lower than those at the crest of the monocline. This evidence suggests that perhaps as much as 100 feet of vertical movement has been absorbed by the intervening incompetent Bright Angel shales. There is no tangible evidence to indicate that movement took place along this branch fault in pre-Cambrian time. Similar *en échelon* faults occur south of this fault, but have a throw of only 200 or 300 feet. At locality 3 (Fig. 3), the post-Paleozoic movement of the original Butte fault is less than the pre-Cambrian movement. The displacement measured on the Tapeats sandstone is 300 feet and the combined

movement by faulting and folding is 700± feet. Near the Colorado River, at locality 4 (Fig. 3), the post-Paleozoic movement on the Butte fault is 300 feet as measured on the Tapeats sandstone ½ mile north of the river. The combined movement by faulting and drag is 700± feet. The post-Paleozoic movement on the Desert View monocline at locality 6 (Fig. 3) is 200–250 feet as measured on the Redwall limestone. The evidence cited shows clearly that the displacement along the Butte fault has been reversed in pre-Cambrian and post-Paleozoic time.

The Butte fault passes into a fold both laterally and vertically. Figure 6 shows a locality at the southern end of the Butte fault where the fractured zone passes laterally into pre-Cambrian folded beds. The beds which are seen in the picture are faulted at a locality 2,000 feet north of the locality shown in the picture, therefore the fault passes into a fold in the intervening interval. Figure 7 is a view at locality 6, approximately 3 miles south of the picture 3, shown in Figure 6, and along the same line of movement. This picture shows the monoclinal fold which has been developed in the Paleozoic strata. A similar fold is developed at the northern end of the Butte fault.

The post-Paleozoic faulting can not be dated accurately because of the lack of sufficient exposures of post-Permian strata. Diastrophic movements are reported[5] to have taken place in the post-Kaibab limestone pre-Moenkopi formation interval in this general region. The presence of a slight angular discordance between the Kaibab and Moenkopi formations, evidence of an erosional interval and fossil evidence, which indicates that the upper Permian is not present in this region, shows that an unconformity is present between the Kaibab and Moenkopi formations. Evidence of diastrophic movements during the late Cretaceous or early Eocene in areas north and east of the Grand Canyon have been reported.[6] Evidence of Quaternary faulting has been reported in the region immediately east of the Grand Canyon.[7] Near the southern end of the Butte fault, three sets of terrace gravels, the highest of which is more than 100 feet above the present level of the Colorado River, occur on each side of the fault. Apparently the faulting is pre-Terrace gravels because any appreciable movement

[5] L. F. Ward, "Status of the Mesozoic Floras of the United States," *U. S. Geol. Survey Mon. 48* (1905), p. 38.
H. W. Shimer, "Permo-Triassic of Northwestern Arizona," *Bull. Geol. Soc. America*, Vol. 30 (1919), pp. 496–97.
George Girty, in J. B. Reeside, Jr., and Harvey Bassler, "Stratigraphic Sections in Southwestern Utah and Northwestern Arizona," *U. S. Geol. Survey Prof. Paper 129* (1922), p. 60.

[6] H. E. Gregory, "Geology of the Navajo Country," *U. S. Geol. Survey Prof. Paper 93* (1917), p. 60.
H. E. Gregory and R. C. Moore, "The Kaiparowits Region," *U. S. Geol. Survey Prof. Paper 164* (1931), pp. 116 and 122.
James Gilluly, "Geology and Oil Prospects of Part of the San Rafael Swell, Utah," *U. S. Geol. Survey Bull. 806c* (1929).
James Gilluly and J. B. Reeside, Jr., "Sedimentary Rocks of the San Rafael Swell and Some Adjacent Areas in Eastern Utah," *U. S. Geol. Survey Prof. Paper 150d* (1928).

[7] Parry Reiche, "Quaternary Deformation in the Cameron District of the Plateau Province," *Amer. Jour. Sci.*, Vol. XXXIV (1937).

since their deposition could readily be detected. It is not known whether the movement along the Bright Angel and Butte faults took place concurrently with any of those mentioned above or whether it was distinct from them.

FOLDS

The regional structure of the pre-Cambrian Grand Canyon series consists of a broad syncline, the axis of which trends northwest and southeast. The dips in the beds are low and less than 15°. The southwestern limb of the syncline has been well exposed by the Colorado River and its tributary canyons and consists of at least three major blocks or wedges of Unkar sediments which are bounded by northwest-southeast-trending normal faults. These blocks form a series of fault-block mountains which existed at the time the Tapeats sandstone was deposited. The sediments of the Chuar group which occur in the trough of the regional syncline, have been deformed by a series of northwest-southeast-trending folds. It is probable that these minor folds are the reflection of faults which may be present in the deeper and more competent beds.

Two small synclines are developed immediately west of the Butte fault. One occurs on the south side of the Colorado River and is clearly shown by the basalts. The sediments of the overlying Nankoweap group occur in the trough of the syncline and both the basalts and the Nankoweap sediments are truncated by the Tapeats sandstone. This syncline is more than a mile wide and the axis trends north and south. The second syncline which occurs in the Chuar sediments immediately southwest of locality 5 (Fig. 3), is approximately ½ mile wide, and the axis trends north and south parallel with the Butte fault. Although the evidence is not entirely conclusive, the proximity of these synclines to the Butte fault, the fact that their axes are parallel with the Butte fault and that they do not conform with the northwest-southeast-trending folds of the Chuar group suggest that they have been developed as a result of the movements along the Butte fault.

The folds which have been developed in the Paleozoic strata are shown on Figure 3 by the contours which have been drawn on the top of the Redwall limestone. The more pronounced folds are the northwest-southeast-trending Grand View and Desert View monoclines, the northeast-southwest-trending Bright Angel monocline, the drag folds which are developed along the Butte fault, and the *en échelon* monoclines which branch toward the southeast from the southern part of the Butte fault. Each of the monoclines observed in this area appears to be definitely related to faulting as every monocline mapped is associated with a normal fault which has essentially the same strike as the monoclinal fold and the downthrown side of the fault corresponds with the downfolded side of the fold. Furthermore, the field evidence shows distinctly that the faults pass laterally and/or upward into the monoclinal folds. In numerous places, fractured competent strata are overlain by folded incompetent shales, indicating that essentially all of the movement has been absorbed by folding rather than fractur-

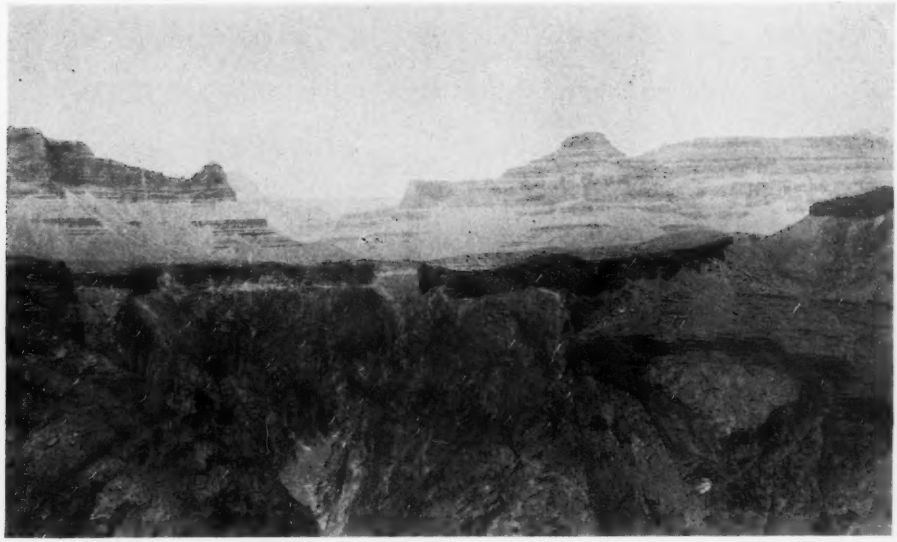


FIG. 4.—Example of pre-Cambrian faulting. Right center of picture shows Unkar sediments on right in fault contact with Archean schists, both of which are truncated by Cambrian Tapeats sandstone.

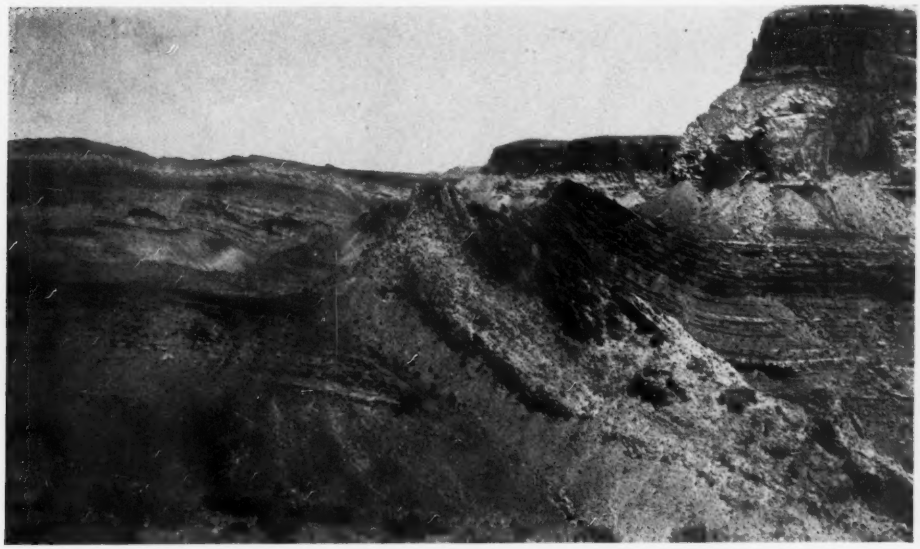


FIG. 5.—View north along Butte fault. Upturned Permian Supai strata on right are in fault contact with Algonkian Chuar group. Throw of Butte fault is approximately 2,200 feet at this locality.

FIG. 6.—Monoclinal fold developed in Dox sandstone at south end of Butte fault. Movement is represented by fractures 2,000 feet north of this picture.

FIG. 7.—View southward at gentle monocline which has been developed in Paleozoic sediments at locality approximately 3 miles south of Figure 6.

ing. The monoclinal folds are believed to have been produced under tension or "lack of compression" rather than compressional forces since they are all associated with normal faulting.

Several closed anticlines and synclines have been developed as a result of the faulting in this area. The regional dip of the Paleozoic strata in this region is toward the southwest. It is obvious that any appreciable amount of folding along a northwest-southeast-trending line of displacement, downthrown on the northeast side, would form an anticline or monocline with a compensating syncline. Since this relationship is shown by the northwest-southeast-trending monoclines and anticlines throughout the area mapped and in some cases a fault which is downthrown on the northeast side can actually be observed in the lower beds, there can be little doubt that the folds have been formed by the process outlined. Movement along transverse northeast-southwest faults has produced closure on some of the anticlines and synclines. The closed part of the Grand View anticline appears to have been formed by a combination of downward folding of the beds along three faults. The Phantom Creek fault produced a northeastward reversal against the regional dip and formed an anticlinal axis whereas the northwestward plunge appears to be the result of downward movement along the eastern side of the Hindu Amphitheater fault. The southeastern plunge appears to have resulted from downward movement along the eastern side of the Vishnu fault.

CONCLUSIONS

A study of the faults and folds in the eastern part of the Grand Canyon region reveals that all of the faults are of the normal type. Several of these faults were active in the pre-Cambrian and two of these faults, the Bright Angel and the Butte, have been active in both pre-Cambrian and post-Paleozoic time. The Bright Angel and the Butte faults are major structural features in this region as the Bright Angel fault has a throw of more than 600 feet and the Butte fault has a throw of more than 2,200 feet. The displacement on both of these faults has been reversed from downward on the western side during the pre-Cambrian movement to downward on the eastern side during the post-Paleozoic movement. The movement which has caused faulting in the lower beds is exhibited as folds in the higher Paleozoic sediments. The Butte fault passes laterally into a fold at its southern end. The Bright Angel and Butte faults have been traced as faults for a distance of 10 to 15 miles; however, the movement along these lines of displacement can be traced several miles farther along monoclinal folds developed in the surface Paleozoic strata.

Normal faulting in conjunction with the regional dip apparently has formed the monoclines, anticlines, and synclines which occur in the Paleozoic strata. Transverse faulting has formed closure on some of the anticlines. The post-Paleozoic faulting in the Grand Canyon can not be dated more closely than post-Permian and pre-Recent Terrace gravels, although evidence in southern Utah along the East Kaibab monocline indicates displacement in the late Cretaceous or early Eocene.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 11 (NOVEMBER, 1946), PP. 1910-1934, 10 FIGS.

GEOLOGICAL NOTES

RELATIONS BETWEEN KINDS OF WELL DATA AND APPARENT FAULTING[1]

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Pointe-a-Pierre, Trinidad, B.W.I.

INTRODUCTION

In the course of a study of salt-dome tectonics, the writer looked at a number of well sections, some extending from surface to 12,000 feet, others showing only the interval between 4,000 and 12,000 feet, and noticed an increase of faulting with increasing depth. On sections ranging to 6,000 feet there appeared to occur more faults near the 5,000-foot level than at shallower depth, and on sections ranging to depths of 10,000–12,000 feet, there appeared to be a maximum of faulting near the 8,000-foot level. On a number of sections from various sources the number of faults was computed. The sections were subdivided into depth intervals of 2,000 feet. The results of the count are plotted on Figure 1, a plot of frequency of faults per section against depth. A fault cutting through various levels (from surface to 4,000 feet, *et cetera*) was counted for each depth interval which it penetrated. No account was taken of the width of a section on the assumption that the various sections checked did compensate each other in width.

The result of the count as shown in Figure 1 seems to indicate that faults increase in frequency at depth. The curve connecting the various points resembles a probability curve and though not shown, there is an indication that the location of the maximum is dependent on the maximum depth range investigated. Unmistakably, on many sections more faults are shown at greater than at shallower depth. Presumably, faults are shown because they are required to explain the geology, yet the suspicion arises—is the relation indicated by the curve (Fig. 1) a true natural one, or is it a fortuitous one, and due to quality and quantity of factual evidence on which sections are based? It is the purpose of this note to find a possible answer to this problem of fault frequency.

POSSIBLE REASONS FOR DEPTH VARIATIONS IN FAULT DENSITIES

In folded areas faults occur in tension and in compression zones; they are practically absent in neutral zones. This is one explanation for the presence or the absence of faults, that is, for variations in density of faulting. Faults are less common in slightly folded than in violently folded areas. In many places folding

[1] Manuscript received, July 2, 1946.

[2] Geologist, Trinidad Leaseholds, Limited.

decreases considerably above an unconformity. Thus, the presence of an unconformity on top of strongly folded and faulted older beds may be responsible for an apparent increase of faults with depth. Of course, many sections show only important or relevant faults, and the lack of faulting at shallower levels of a section may have no tectonic meaning; the draftsman simply did not wish to show

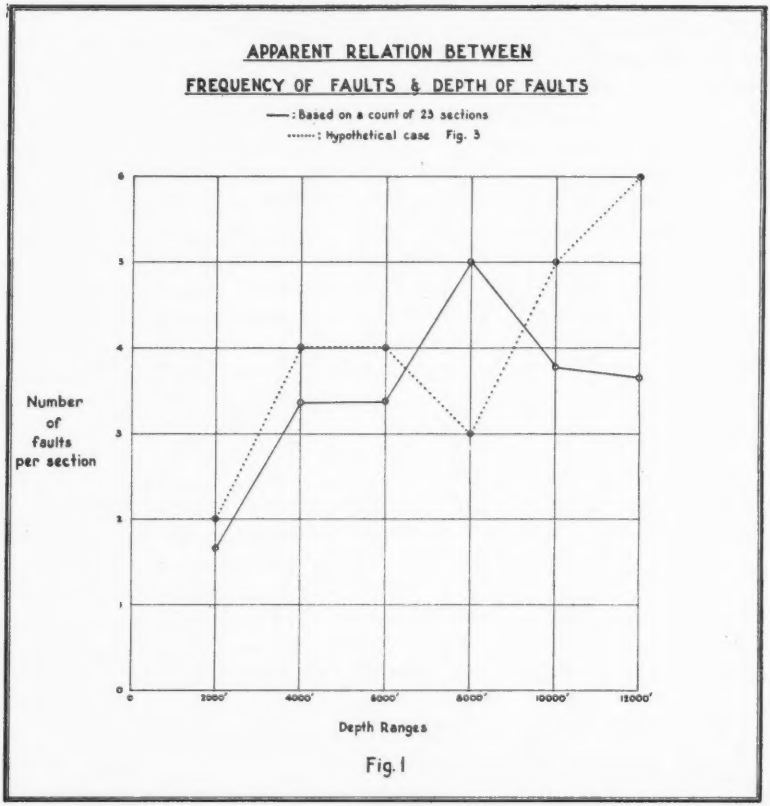

Fig. 1

shallow faulting or due to lack of information may not be able to show faults. Nevertheless, after elimination of doubtful cases, there still remains a conspicuous number of sections showing less faults at shallower than at greater depth. This is especially noticeable on some salt-dome sections. Some of these contain clusters of faults at certain levels for which there is no apparent explanation. Perhaps, an analysis of a hypothetical case may explain the situation better and perhaps it may yield an explanation for this phenomenon of fault distribution.

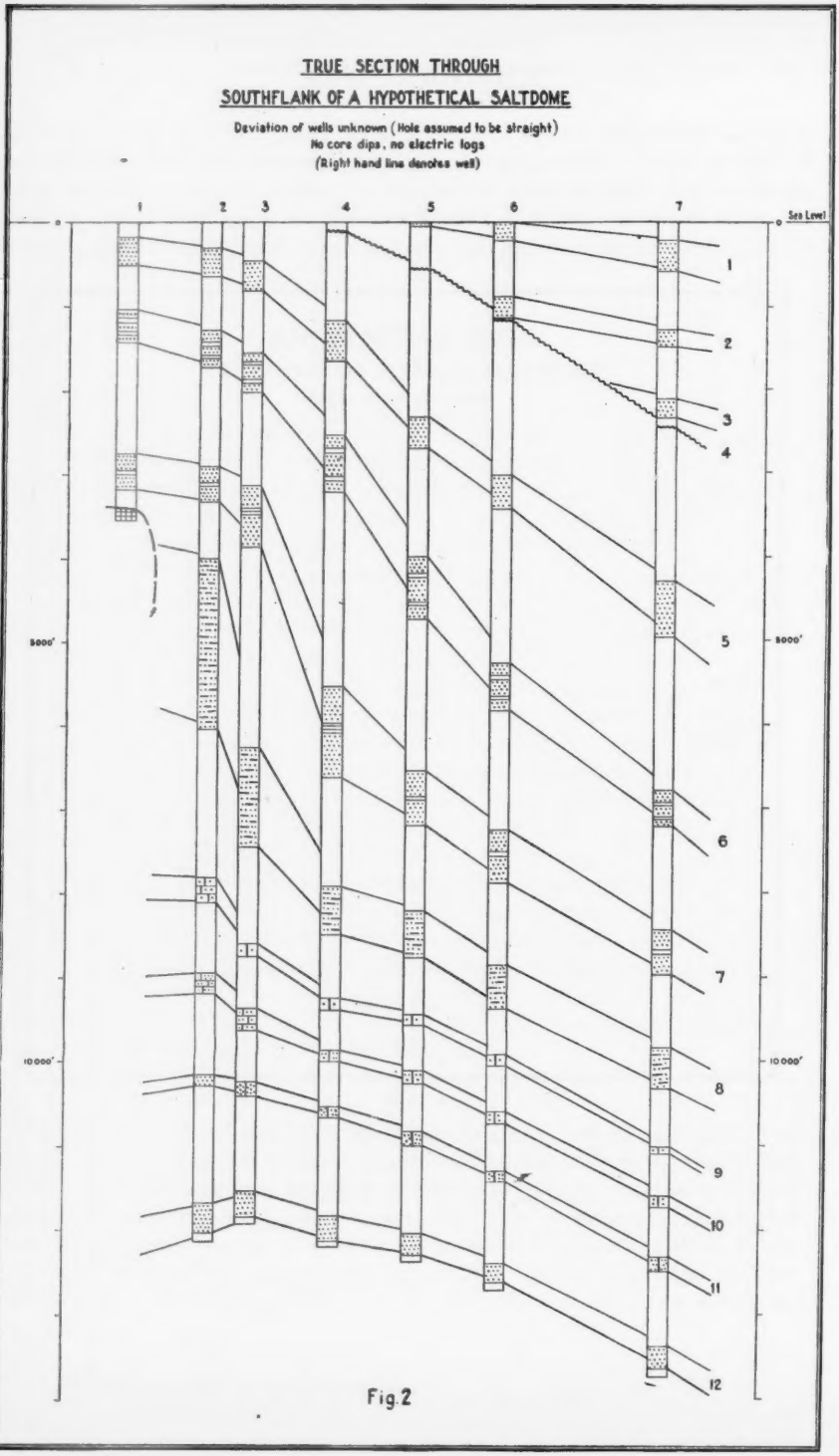
TRUE SECTION THROUGH
SOUTHFLANK OF A HYPOTHETICAL SALTDOME
Deviation of wells unknown (Hole assumed to be straight)
No core dips, no electric logs
(Right hand line denotes well)
1
2
3
4
5
6
7
Sea Level
0
5000'
10000'
1
2
3
4
5
6
7
8
9
10
11
12

Fig. 2

FAULTING ON HYPOTHETICAL SALT DOME (Figs. 2, 3, and 4)

Faulting on a hypothetical salt dome is analyzed by means of a set of three sections, being alternative versions of one and the same section through the south flank of a hypothetical dome.

Version No. 1 (Fig. 2). Wells straight, logs based on ditch samples only.—The assumption is made that all wells are located on or close to a section line to permit direct projection. Further, it is assumed that all beds penetrated have an individuality permitting straightforward correlation. The wells are considered to be vertical to the bottom. No cores are available; in other words, the wells are of the pre-coring, pre-Schlumberger age. The resulting correlation and the structural picture are simple and clear and apparently perfectly logical. There is a south flank, steepening at depth but disappearing at the 10,000-foot level. Wells 2, 3, and 4 seem to have penetrated an anticline, presumably below an undetectable unconformity. There is nothing in oil and water distribution to indicate any anomaly. However, the production history later shows that Wells 2, 3, and 4 developed abnormally steep declines. Exploitation proceeds on the assumption that reservoirs are continuous. The fact that Well No. 3 (Sand 12) went first to gas seemed to confirm structural interpretation. Apparent changes in thicknesses of beds were explained by lenticularity.

Version No. 2 (Fig. 3). Wells straight, logs based on cores.—It is now assumed that the same set of wells shown on Figure 2 has been cored sufficiently to permit construction of a section based on core data. The interpretation of the logs has taken account of dips as measured in the cores. These dips are of course apparent only and differ in various degrees from the true formation dips. A comparison of Figures 3 and 4 reveals that some of these apparent core dips are steeper, while some are flatter than the true formation dips. In our hypothetical case, differences between apparent and true core dips vary from $-23°$ to $+9°$. In the two extreme cases the apparent dip is 23° flatter than the true dip in a well drifting updip and 9° steeper in a well drifting downdip.

Since the direction of the dip is still not known, it is assumed that all sands dip south in accordance with the surface dips. The picture resulting from this set of data is shown on Figure 3. The interpreter was forced to introduce a number of faults in order to explain the many anomalies. The flank appears to be cut up into small fault blocks, resulting in many reservoirs, some of them penetrated by one well only. Consequently, for most of the wells an individual production policy had to be formulated and adopted. The sands now appear less lenticular, almost of constant thickness; in other words they are sheet sands.

What is of special interest here is the resulting fault pattern, the apparent increase in the number of faults with increasing depth. On Figure 1 this increase is plotted and shown to be appreciable, though difficult to explain, as there is no evidence for other unconformities than the one cutting Wells 4 to 7 at shallow depth. However, the structural picture appears logical since on a salt dome one

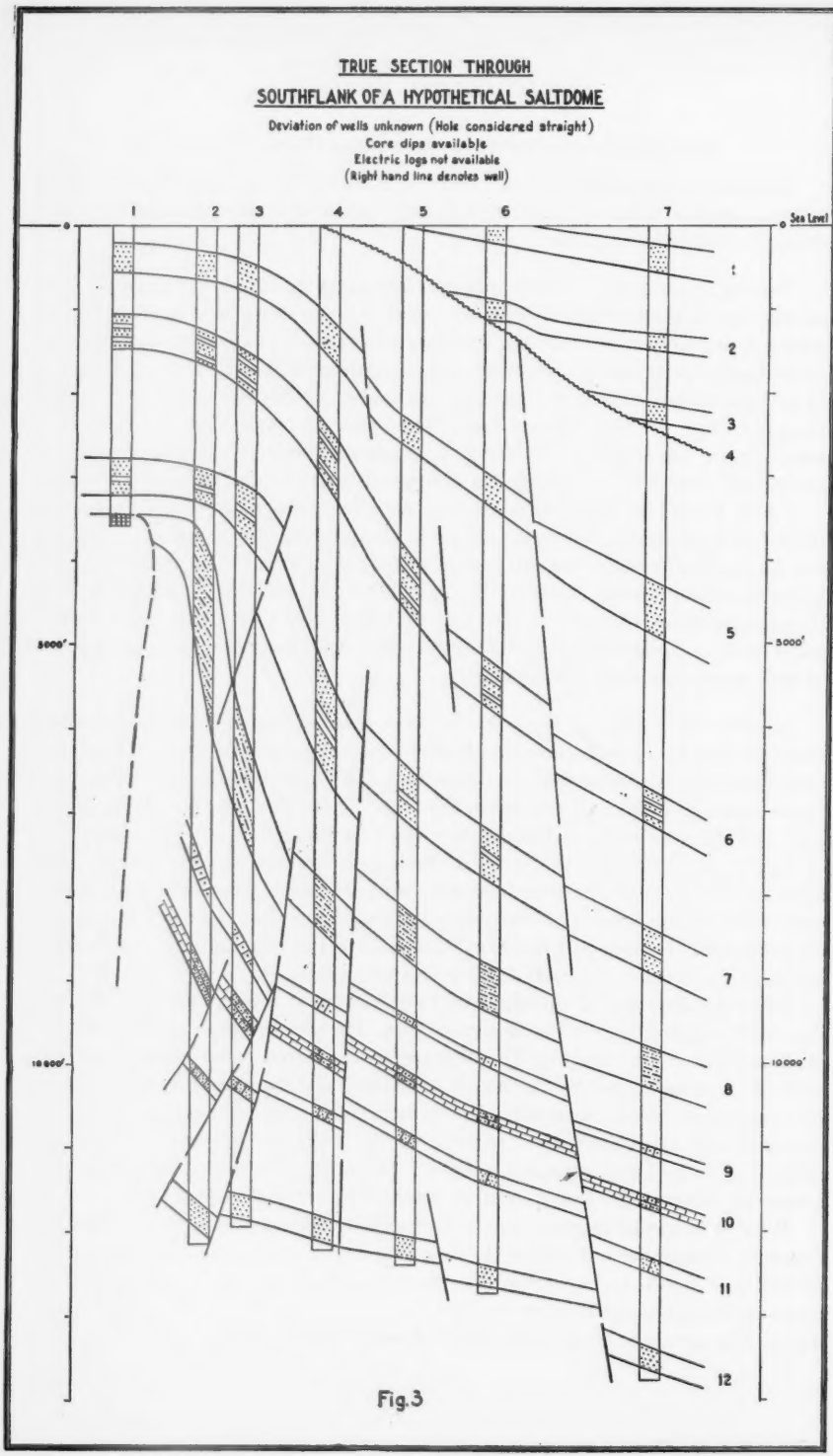
TRUE SECTION THROUGH
SOUTHFLANK OF A HYPOTHETICAL SALTDOME
Deviation of wells unknown (Hole considered straight)
Core dips available
Electric logs not available
(Right hand line denotes well)
1
2
3
4
5
6
7
Sea Level
0
5000'
10000'
1
2
3
4
5
6
7
8
9
10
11
12

Fig.3

TRUE SECTION THROUGH

SOUTHFLANK OF A HYPOTHETICAL SALTDOME

Core-Dips and Well deviations
adjusted to plan of section
Electric logs available

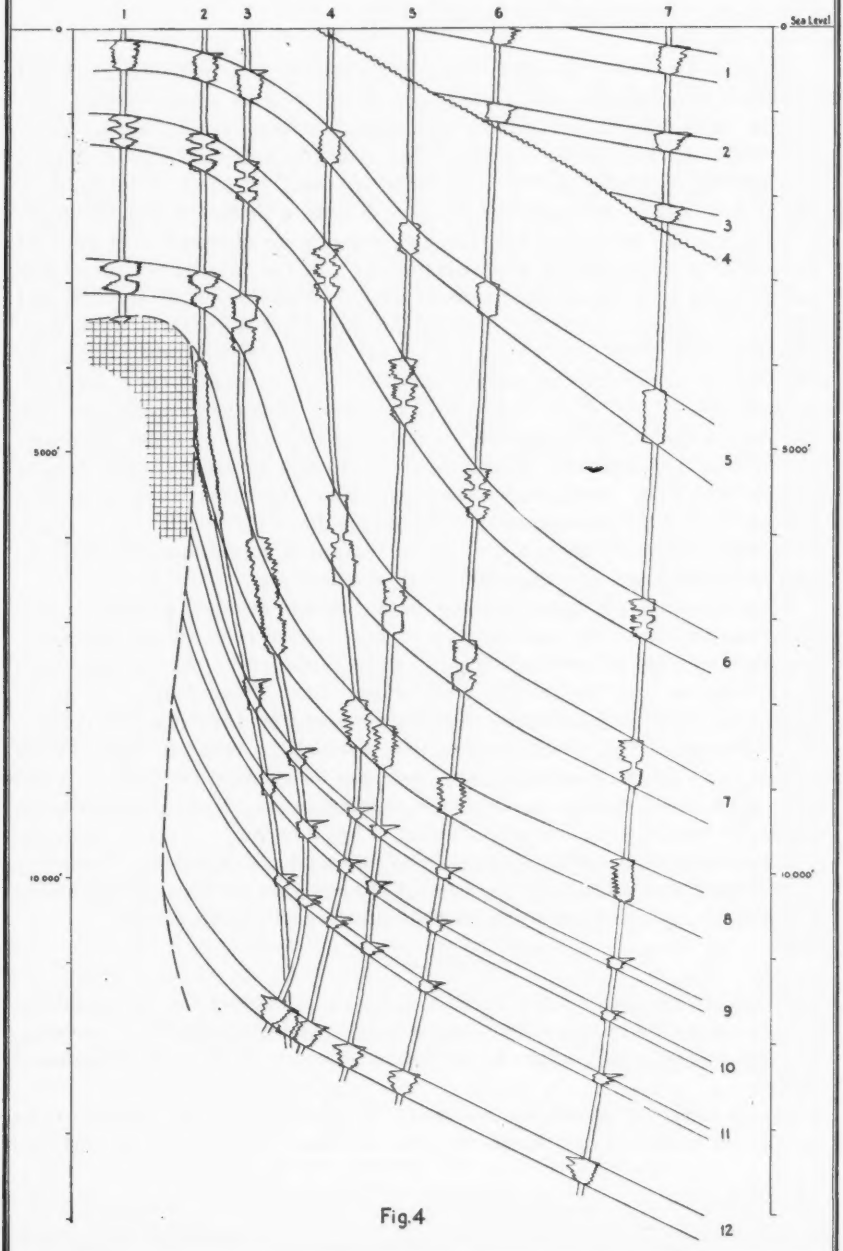

Fig.4

can expect collapse faults dipping toward the salt core, causing displacement downward as the core is approached. Only a long production history permits criticism and correction of this picture.

Version No. 3 (Fig. 4). Wells deviated, electric log, cores and electric dip and deviation survey available.—It is a long known fact, now an axiom, that all wells deviate. The amount of deviation or drift depends on many factors, among which the human factor is not the most important one. Dip, compaction of formation, stratigraphic sequence (hard and soft beds), *et cetera*, all affect deviation. In a section with a fairly homogeneous sequence of beds of similar competency tends to deviate updip for dips of less than 45°, downdip for dips exceeding 45°, and transversal in beds dipping approximately 45°. In the hypothetical case, it is assumed that all wells deviated more or less in the section plane. Hypothetical deviations range between 0.25° and 23° for individual segments of 1,000 feet. Resulting over-all deviations vary per well between 0° 30′ (practically a straight hole) and 6° 30′ (still a very modest deviation). The average over-all deviation per well works out at 3° 42′, the over-all deviation being the deviation from the vertical of a straight line connecting the top of the well with its bottom. This over-all deviation is a fallacious figure because it can hide a rather crooked hole as hypothetical Wells 2 and 3 show. The hypothetical deviations can be considered as realistic and not uncommon, since a seemingly modest deviation of 1° per 1,000 feet additional throws a well 10° off vertical at 10,000 feet and results in an average deviation over the entire depth of hole of 5.5°.

The interpretation based on these data, namely, deviated position of well direction, amount of dip, and electric characteristics of beds, shows that stratigraphic anomalies (of the first version) can be explained by the changes in dip of the beds and that the structure resolves itself into a simple south flank free of faults other than the main fault separating the core from the flank. The position of the bottom of Well 2 downdip from that of well No. 3 eliminates the need for introducing a subsurface anticline or a fault, and the clustering of Wells 2, 3, and 4 at depth would explain an anomalous production history. Deviation also explains the seemingly abnormal electric log of bed 8 in Well 2, since it is obvious that the electrode traced an average of clay and sand in this horizon. The survey of well deviations led to the abandonment of horizon 12 in Wells 3 and 4 and to a production policy of producing all wells of each horizon as a group.

CONCLUSIONS

From the comparison of Figures 2, 3, and 4, it appears that an additional explanation for the apparent frequency of faulting at depth might be forthcoming, namely, this frequency might be artificial and due to undetected deviation of wells.

If the foregoing explanation be correct, it follows that no well section can be considered reliable unless based on fault evidence from electrically surveyed

holes, this survey to include one of verticality, especially in deeper wells. Of course, conventional core data checked against an electromagnetic or an S.P. dip survey is still helpful, and for many problems it is indispensable, quite apart from the necessity of procuring cores for physical or petrographical data.

The hypothetical case discussed is a very simple one; even so, it should demonstrate the necessity for careful evaluation of faulting. It is easy to see that a more complicated case, that is, one of wells deviating variably away from the section and with actual faults present, plus lenticular beds, on insufficient information, would result in a much more fallacious picture than those shown on Figures 2 and 3.

It now appears that at least in scientific papers the geologist must perforce become more definite in stating his premises. It is very necessary on scientific well sections to indicate either graphically or in a footnote to what extent the section is based on sufficient data, for example, core dips must be differentiated from formation dips, the subsurface position of the bottom of the borehole must be clearly shown on maps and sections in all cases where deviation exceeds the limits of scale. Failure to take account of relevant information may lay a geologist open to the accusation of over-simplification or unscientific procedure.

ATLANTIC COASTAL PLAIN FLOOR AND CONTINENTAL SLOPE OF NORTH CAROLINA[1]

W. F. PROUTY[2]
Chapel Hill, North Carolina

Very little has been known about the floor of the Coastal Plain of North Carolina until recently. At the time of the drilling of the Havelock well, near New Bern, only six wells had been drilled to the basement rocks in North Carolina and four of these were comparatively shallow wells, nearer the Fall line than the Coast.

Early in 1934 a magnetometer traverse was run by members of the department of geology of the University of North Carolina, from Myrtle Beach to a point a few miles west of Florence, South Carolina. This survey showed that the highly magnetic rocks of the Coastal Plain floor shallow evenly and rapidly from the Coast to a point a few miles northwest of Conway, South Carolina, and a steady but less rapid increase in the rise of the floor from there to the eastern edge of the buried Triassic basin near Florence, South Carolina. This magnetometric demonstration of the two gradients in the Coastal Plain floor was strengthened by evidence from the two deep wells near the Coast, one in Wilmington and the

[1] Manuscript received, August 6, 1946.

[2] Head of department of geology and geography, University of North Carolina.

other a few miles south at Fort Caswell, near Cape Fear, North Carolina. Here the gradient of the floor was shown to be much steeper than it is inland from Wilmington.

When the Havelock well, which is located about 32 miles north of west from Cape Lookout, was drilled to a depth of 2,318 feet to the crystalline floor, its depth showed the floor at that point to be deeper than one would expect from the general gradient as established by the three wells northwest of Havelock. The deep well at Morehead City, located about 14 miles southeast of Havelock,

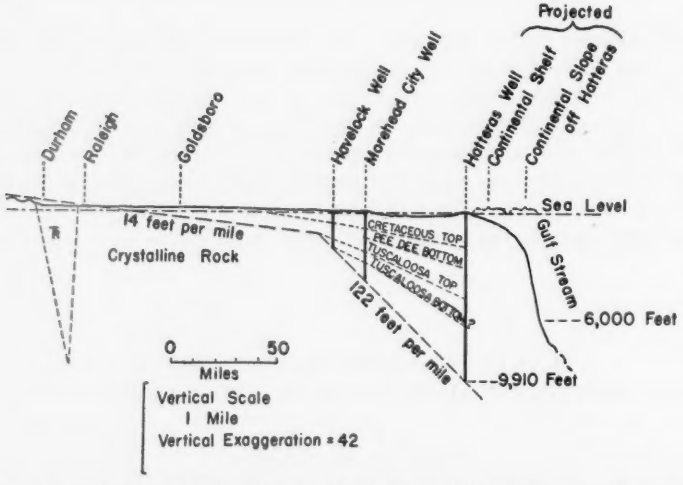

FIG. 1.—Generalized cross section through Atlantic Coastal Plain, as shown on Figure 2, giving the gentle and the steeper floor planes, relative position and depth of the three wells and continental shelf and slope near Hatteras, all projected onto line of cross section, parallel with line of intersection of two floor planes. Source of formational data: Havelock well from H. G. Richards, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), p. 913; Morehead City well, tentative correlation notes, H. G. Richards; Hatteras well, tentative correlation field notes, Standard Oil Company (N. J.).

which reached the crystalline basement at 4,044 feet, suggests a gradient of the basement between this well and the Havelock well to be about 122 feet per mile. This later drilling confirms the earlier evidence gained from the Wilmington and Fort Caswell wells and the magnetometer cross section from Myrtle Beach to Florence, and clearly demonstrates the presence of two persistent slopes in the floor of the Coastal Plain, the steeper one nearer the ocean.

From this evidence and the hypothetical position of the intersection of these two slopes (Fig. 1), assumed to be planes, a generalized cross section was drawn in the early spring of 1946 before completion of the Hatteras Light well No. 1. This section extended from the Piedmont near Durham, North Carolina, through

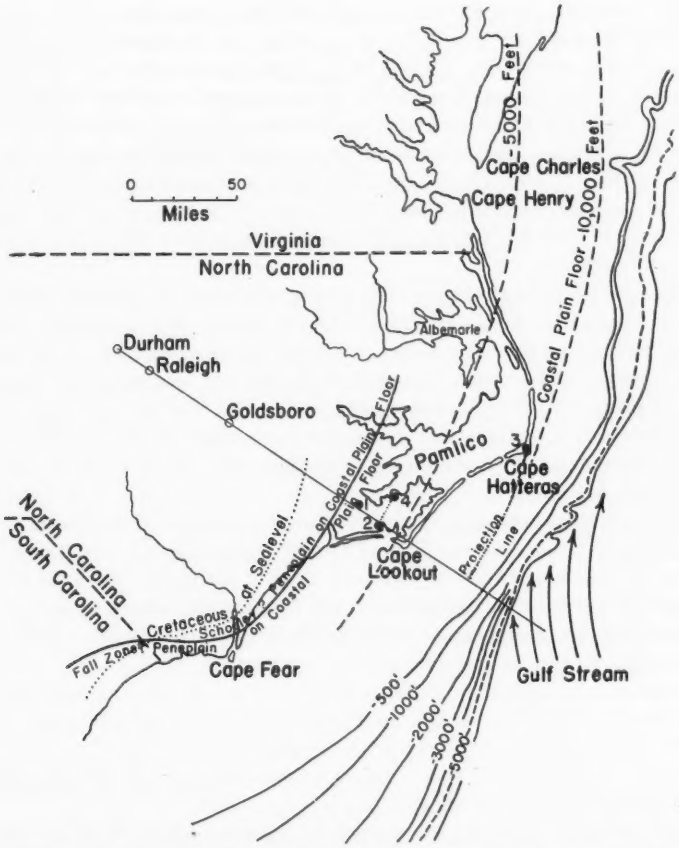

FIG. 2.—Map of Middle Atlantic Coastal Plain showing: location of four near-coast deep wells which have reached crystalline floor; position of cross section (Fig. 1); top of Cretaceous at sea-level; theoretical position of line of intersection of two floor planes; theoretical contours of −5,000 feet and −10,000 feet on the Coastal Plain floor; and apparent steepening by submarine erosion of continental slope off Hatteras area, as shown on Tectonic Map of United States. Well numbers: *1*, Havelock well; *2*, Morehead City well (Carolina Petroleum Company well No. 1); *3*, Hatteras Light well No. 1; *4*, Carolina Petroleum Company well No. 2.

the Havelock and Morehead City wells (Fig. 2). Onto this cross section the Hatteras Light well No. 1 of the Standard Oil Company (New Jersey), as well as the continental shelf and slope southeast of Hatteras, was projected along a line parallel with the assumed line of intersection of the two floor planes.[3]

[3] Paper given before Geological Society, University of North Carolina, March, 1946, and The North Carolina Academy of Science, May 3, 1946, by W. F. Prouty.

When the drilling in the Hatteras Light well No. 1 later reached the crystalline floor of the Coastal Plain at a depth of 9,910 feet,[4] it was found that its predicted depth as shown on the cross section (Fig. 1) was practically correct. This single verification of the general correctness of the assumed structure of the Coastal Plain floor, shown in Figures 1 and 2, has since been further verified by the second well of the Carolina Petroleum Company, which reached the crystalline floor, near Merrimon, at a depth of 4,070 feet. This latter well is located also on the steeper plane and practically along a level line on this plane (strike), about 15 miles N. 20° E. from the Carolina Petroleum Company's well No. 1 ("Morehead City" well) (Fig. 2).

The more gentle and the steeper sloping planes of the Coastal Plain floor, previously indicated, are interpreted as the Schooley, or some earlier peneplain and the Fall zone peneplain, respectively. In the generalized cross section, the Schooley peneplain has a gradient of about 14 feet per mile and is represented by erosional remnants in the Piedmont west of the Fall line for some distance. The line of intersection of these two planes seems to approach and finally cross the Fall line northeastward from the cross section (Fig. 2), probably in the upper Chesapeake Bay region.

The oceanward extension of the general cross section from Hatteras, made from data taken from Tectonic Map of United States,[5] shows a very rapid descent into the deep ocean less than 30 miles southeast of Hatteras with slopes of several hundred feet per mile. The presence of the Gulf stream within 20 to 25 miles of the shore and the configuration of the depth lines on the Tectonic Map suggest active erosion of the continental shelf in this area (Fig. 2).

Attention is called to the probable outcrop of much of the Upper Cretaceous, as tentatively identified, on the continental slope off Cape Hatteras (Fig. 1). Also the map position of the sea-level contour on the top of the Cretaceous is here shown to be (Fig. 2) much different from that on the recently published Tectonic Map of the United States.

The contour of 5,000 feet below sea-level and the contour of 10,000 feet below sea-level, shown on Figure 2, are drawn on the assumed steeper floor plane (Fall zone peneplain).

[4] Completion and depth announced by Standard Oil Company (New Jersey), July 10, 1946.

[5] Published by the American Association of Petroleum Geologists (1944).

GRAIN SIZE IN CARBONATE ROCK[1]

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INTRODUCTION

From June to November, 1945, W. E. Ham of Norman, Oklahoma, and the writer corresponded on the subject of grade scales for carbonate rocks. They did not reach agreement. The opinions and preferences expressed in this note are the writer's, but a large part of whatever clarity and merit they have attained is due to the discussion with Ham.

The purpose of this note is to raise the question of how best to describe the sizes of carbonate grains, not to solve the problem finally. A critical review of certain textural terms is attempted and some tentative suggestions are made.

Carbonate rocks are rocks, such as limestone and dolomite, composed largely of carbonate minerals. The grade scales for clastic rock are not suitable for carbonate rock, because the names of the scale units imply the clastic origin of the rock. Some carbonate rocks are clastic; that is, they are formed of fragments of older rocks. Even with regard to these it would be ambiguous to speak of clay grains or silt grains or sand grains. Carbonate grains could be periphrastically described, however, as "of clay size," "of silt size," "of sand dimension," and so forth.

An adequate scale for carbonate rocks would probably serve for the sulphate and chloride rocks as well, and perhaps also for chert and novaculite. Indeed the need appears to be for a scale of grain size without implications of origin.

DEFINITIONS AND CRITICISMS

Crystalline.—One aspect of crystallinity is internal molecular configuration, which differentiates crystalline solids from glasses. Payne[3] contrasts fragmental-textured and crystalline-textured rocks. The latter hyphenated adjective implies that the grains of the rock are more or less recognizable as crystals. It is hardly adequate to describe carbonate rocks composed of oölitic grains or fragments of older rocks. Some subsurface geologists in West Texas describe certain textural features of carbonate rocks other than grain size by contrasting the terms *granular* and *crystalline.* To describe a carbonate rock composed of grains of fine sand size as "finely crystalline" implies more than grain size. Therefore, *crystalline* is an unsuitable term for a carbonate grade scale.

Granular.—Because of past usages by geologists *granular* also implies more than that the rock is composed of grains. In the Wentworth scale granules range

[1] Manuscript received, August 26, 1946.

[2] Argo Oil Corporation.

[3] Thomas G. Payne, "Stratigraphical Analysis and Environmental Reconstruction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 11 (November, 1942), Table III, p. 1706.

in size between very coarse sand grains and pebbles. Payne used the phrase *granular crystalline* for this grade. Geologists should not use such terms as *microgranular* without defining them.

Grained.—The adjective *grained* may be used to describe any rock composed of grains. In many contexts it will be understood and can be omitted. Thus, a coarse-grained oölite can be described as a coarse oölite, and a cryptograined crystalline specimen can be called cryptocrystalline. *Grained* is an everyday English word, which descended from Latin through Old French, whence it gained its "i." The seeming miscegenation in such words as *micrograined* is not greater than is desirable in the melting pot of science.

Lithographic.—The term *lithographic* is very useful and will continue to be

TABLE I

Diameter Microns	*Number of Grains*	*Cumulative Diameter*	*Percentage of Grains This Size*	
11.90	8	95.20	1.68	1.9
10.20	1	10.20	0.21	
8.50	8	68.00	1.68	
7.65	2	15.30	0.42	9.8
6.80	23	156.40	4.82	
5.95	14	83.30	2.93	
5.10	34	173.40	7.13	
4.25	39	165.75	8.18	34.4
3.40	91	309.40	19.08	
2.55	78	198.90	16.35	
1.70	109	185.30	22.85	39.2
0.85	70	59.50	14.67	14.7
	477	1,520.65	100.00	100.0

1,520.65/477=3.19 microns=0.0032 mm. mean diameter.

widely used. It implies, however, more of texture than grain size. It connotes smooth fracture and potential commercial use.[4] It would hardly be applied to a chalky limestone. It can be used only to describe the rock in aggregate and can not be applied to the individual grains. These considerations also suggest the occasional inadequacy of some of the terms in the standard grade scale for "fragmental-textured" rocks. Lithographic carbonate rocks are probably clastic, but who would call lithographic limestone a clay? Or a novaculite a claystone?

The mean grain diameter in typical lithographic limestone is approximately 0.003 millimeter. W. A. Waldschmidt made the following grain count (Table I) of a thin section of Solenhofen limestone; the specimen was obtained from Ward's Natural Science Establishment, Rochester, New York.

Two definitions of lithographic are proposed: (1) pertaining to the stone used

[4] P. E. Cloud, Jr., V. E. Barnes, and Josiah Bridge, "Stratigraphy of the Ellenburger Group in Central Texas—A Progress Report," *Univ. Texas Pub. 4301* (June, 1945), p. 136.

in lithography, "a compact fine-grained yellowish or grayish limestone, *lithographic limestone* or *stone*, the best variety of which is found at Solenhofen, Bavaria, in the Jurassic system";[5] (2) pertaining to compact carbonate rocks having approximately the same grain size and textural appearance as the stone used in lithography.

Sublithographic.—*Sub* and *super* go best with Latin roots; *hypo* and *hyper*, with Greek. *Subaqueous* and *hypodermic* are commonplace examples. *Sublithographic*, a Latin-Greek hybrid, is a recent coinage that has gained a certain currency in geologic literature. It belies its first impression; for it does not refer to rocks finer than and below lithographic in the grade scale. It means "somewhat coarser than lithographic." A grade scale for carbonate rocks would provide a grade name that would make this malformed pentasyllable unnecessary.

NATURAL TWO-FOLD GRADE SCALE: APHANIC AND PHANERIC

Ham pointed out that grains as small as 0.03 mm. in diameter were "clear to moderately clear" to the unaided eye with normal 20/20 vision in artificial or subdued natural light, and "clear" in bright sunlight or under a hand lens, and "very clear" under a 10-power binocular microscope. Grains between 0.03 and 0.004 mm. in diameter he described as follows.

Artificial or subdued light	Indiscernible
Bright sunlight	Faint to very faint
Hand lens	Clear to moderately clear
Binocular	Clear

Thus, Ham has established a natural division for field work. He illustrated this boundary by two specimens with grain diameters of 0.03 and 0.01 mm., respectively. The writer believes that if desirable the dividing line can be placed at either figure or in between.

The adjective *aphanitic* is used by a number of geologists to describe exceedingly fine-grained carbonate rocks. Since *aphanitic* also means "pertaining to aphanite," it is proposed that rocks above and below the natural boundary be described as phaneric and aphanic, respectively.

This proposal provides a simple two-fold grade scale that applies to grains either individually or in the aggregate. One may speak of "aphanic grains" or of "an aphanic rock."

GEOMETRIC INTERVALS

Krumbein and Pettijohn[6] "believe that a grade scale based on a fixed geometric interval and flexible enough to afford a number of relatively small sub-

[5] *Webster's New International Dictionary of the English Language*, 2d edition, unabridged, G. & C. Merriam Company (1934).

[6] W. C. Krumbein and F. J. Pettijohn, *Manual of Sedimentary Petrography*, D. Appleton-Century Company, New York. Chap. 4, pp. 76–90 (1938).

grades is to be preferred." The boundary values of geometric intervals form a geometric progression, such as: a, ar, ar^2, ar^3, ... The symbols a and r stand for constants: a is any constant; r is the constant ratio or radix. If the number of terms in such a progression is n, the formula for the last term L is:

$$L = ar^{n-1}.$$

This may be written

$$\log L = \log a + (n-1) \log r.$$

In many grade scales (Wentworth's and Alling's for example) $a = 1$ and the formulas become:

$$L = r^{n-1}$$
$$\log L = (n-1) \log r.$$

In Wentworth's well known grade scale for clastic rocks, the unit of measurement is one millimeter, the radix r is 2, and n varies by integral steps from minus 7 to plus 9 so as to create 17 boundary values. These define sixteen grades and fix a single boundary for two additional grades: a lower boundary for boulder size and an upper for clay size. Instead of sixteen names, however, Wentworth proposed only six for the range between 256 and 1/256 mm., but he increased these to eleven by differentiating five different grades of sand.

n	L mm.		
		BOULDER	
9	256		
8	128	COBBLE	
7	64		
6	32	PEBBLE	
5	16		
4	8		
3	4	GRANULE	
2	2		
		Very coarse	
1	1		
		Coarse	
0	1/2		
		Medium	SAND
−1	1/4		
		Fine	
−2	1/8		
		Very fine	
−3	1/16		
−4	1/32		
−5	1/64	SILT	
−6	1/128		
−7	1/256		
		CLAY	

Alling[7] proposed a grade scale in which the unit of measurement is likewise one millimeter, but the radix r is 10, and n varies by integral steps from minus

[7] Harold L. Alling, "A Metric Grade Scale for Sedimentary Rocks," *Jour. Geol.*, Vol. 51, No. 4 (May-June, 1943), pp. 259–69.

3 to plus 4 so as to define seven grades (Fig. 2). Each of these major intervals he subdivided into four subgrades by allowing n to vary by quarter-integral steps: for example, -3, $-2\frac{3}{4}$, $-2\frac{1}{2}$, $-2\frac{1}{4}$, -2 $\cdots$.

Alling explicitly limited his proposed grade scale for use in thin-section and polished-section measurements of grain size. Obviously the average of measurements of grain diameters in a thin section is less than the average of the actual diameters of the same grains. The Wentworth scale has been used in recording

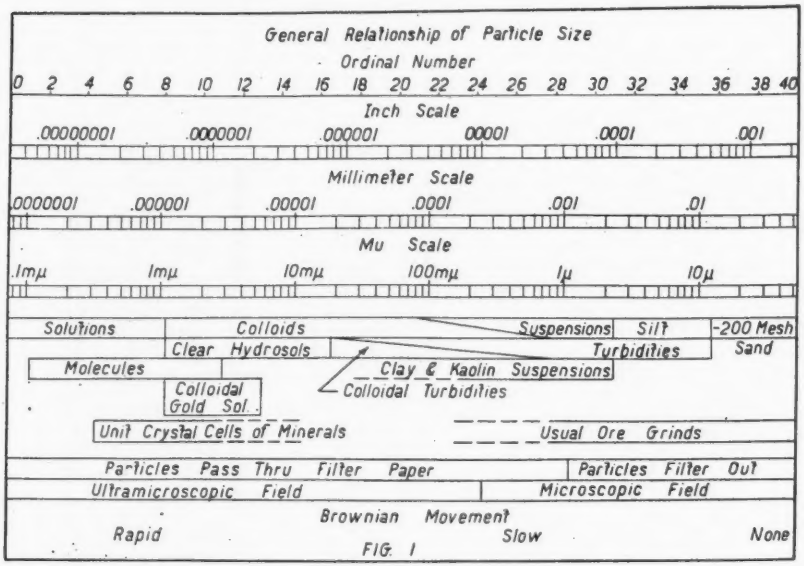

FIG. 1.—From Arthur J. Weinig, "A Functional Size-Analysis of Ore Grinds," *Colorado School Mines Quar.*, Vol. 28, No. 3 (July, 1933). The "Mu scale" is in microns. The "ordinal numbers" correspond with the exponent n in Weinig's scale: unit, one millimeter; radix, $r=\sqrt{2}$; constant, $a=8.42937/10^8$. Reproduced by permission of author.

the diameters of three-dimensional grains. In Alling's view the use of the two different scales would help to avoid confusion. It is true that the two methods of measurement yield different means, modes, and medians of grain diameter. But there are still other methods, each yielding different means and medians. A common one is to classify the sample mechanically according to grain size, weigh the different fractions, and then to plot weight frequencies as ordinates against Wentworth grade units as abscissas. The resulting median grain size is larger than the median determined by a direct count of the frequencies of the diameters of three dimensional grains. Must a third grade scale therefore be invented? And a fourth and a fifth? The use of different scales sheds no light on the relation

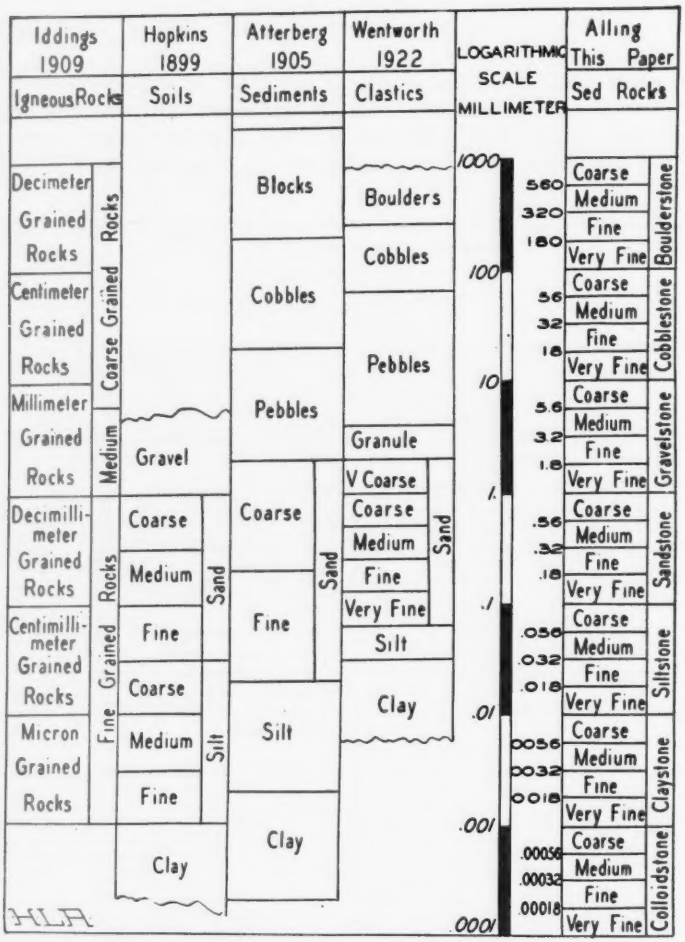

FIG. 2.—Plot of five scales for various purposes including the proposed scale for sedimentary rocks. Logarithmic scale, in millimeters

Iddings, J. P. 1909. *Igneous Rocks*, Vol. I, p. 192. New York: John Wiley & Sons.
Hopkins, C. G. 1899. *U. S. Dept. Agric., Dept. Chem. Bull. 56*, pp. 64–66.
Grabau, A. W. 1913. *Principles of Stratigraphy*, p. 287. New York: A. G. Seiler & Co.
Wentworth, C. K. 1922. *Jour. Geol.*, Vol. XXX, p. 384.
Alling, Harold L. 1942. *Jour. Geol.*, Vol. LI, p. 266.

From *Jour. Geol.*, Vol. 51, No. 4 (May–June, 1943), p. 266.
Reproduced by permission of Harold L. Alling and the University of Chicago Press.

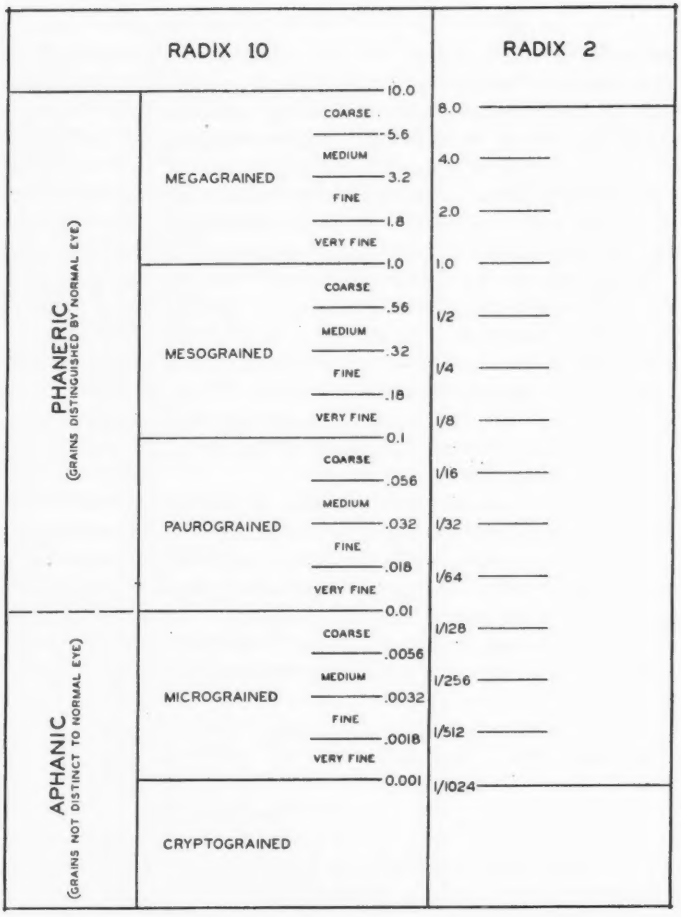

FIG. 3.—Tentative grade scale for carbonate rocks, grain diameters in millimeters, plotted logarithmically. Scale based on radix 2 (used by Wentworth) added for comparison.

between the results of the different methods. It appears that the simplest procedure is always to state precisely the kind of measurement made.

Alling's scale, however, has an orderly simplicity and appears to be mnemonically superior to Wentworth's. It is surprising that quantitative scales are still so little used in routine commercial work. They should be advocated. Alling's scale would be about as easy to introduce at this stage as Wentworth's, for clastic as well as for carbonate rocks.

GRADE SCALE FOR CARBONATE ROCKS

In establishing a scale of grain size for carbonate rocks the problem is threefold: (1) to choose a "number of relatively small subgrades"; (2) to name these; (3) to gain general acceptance and use of the proposed scale.

The problem can not be solved here and now. It is hoped, however, that the suggestions made will aid in the solution. Aspects *1* and *3* will at first prove somewhat contradictory. Many a geologist who now accepts the eleven divisions of the Wentworth scale as a matter of course (although he may not use it) will object to five major divisions in a scale of carbonate grain scale as "too complicated" for practical use. For his use the two-fold division into aphanic and phaneric is recommended, and he is requested to recognize the need that others may have for further subdivision.

The question of naming is even more delicate. Some of the names here suggested probably leave something to be desired. If the Alling scale (Fig. 2) is preferred, an attempt should be made at improving the names. If there is opposition to both scale and names, a new start should be made from the beginning. Figures 1 and 2 should aid in the endeavor.

The prefix *pauro-* means "small"; the *aur* is pronounced[8] like the *or* in orb. If no term were stated, *mesograined* would be understood: thus a "fine crystalline limestone" would be understood to have grain diameters between 0.18 and 0.32 mm. *Mega-* is preferred to *macro-*, because *macro-* may be too easily confused with *micro-*. One may speak either of the aggregate or of individual grains: of micrograins, of a micrograined limestone, or of a limestone with both micro- and paurograins. Oölites are mesograined; a pisolith is a megagrain.[9]

[8] *Webster's, op. cit.*

[9] Ronald K. DeFord and W. A. Waldschmidt, "Oölite and Oölith," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 9 (September, 1946), pp. 1587–88.

USE OF QUOTATION MARK IN SCIENCE[1]

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Most geologists have used the quotation mark[3] chiefly in its basic scientific meaning, which is to delimit a quotation from another person adequate to show faithfully his data or ideas. In recent years, however, there has been an incipient tendency to regard the quotation mark as an omnibus. One result has been occasional use of the mark to isolate a word or phrase from its context, not to show

[1] Manuscript received, September 26, 1946.

[2] Consulting geologist, 2062 North Sycamore Avenue.

[3] "One of the marks used in printing and writing to indicate the beginning and the end of a quotation."—*Webster's Collegiate Dictionary*, Fifth edition (1940).

data or ideas of the person quoted, but to give the word or phrase a meaning different from that in which it was used. There is some question whether lifting a word and framing it in quotation marks to imply a meaning other than that of the person quoted constitutes an adequate quote. As a contribution to this and other questions some usages of the quotation mark are here outlined for consideration.

The basic and always legitimate usage of the quotation mark in science is at the beginning and at the end of a direct quotation of sufficient length,[4] bearing, or other quality to show as accurately as possible the data or opinion, or as reasonably accurately as extract quotation may permit the substance or essence of these, of the person quoted. Complete justice in a highly abstract quotation is almost impossible to attain because of elsewhere qualifying statement by the person quoted which in some degree, however small, usually precludes this in an absence of full quotation. Wholly legitimate variations of the basic usage that exist, such as quoting titles or abbreviated usage, are confined to those which do not distort or otherwise change the meaning of words quoted.

A second, minor, and dangerous usage is to lift and quote an isolated word or short phrase to show subject, the isolation being theoretically neutral, devoid of derogatory implications. If the slightest antagonism is displayed when lifting to show subject, the word or phrase lifted will acquire, as a modifier, one or more other shades of meaning. It is difficult for an author on one side of a question to isolate and quote a word or phrase from an opposing argument to show subject without also showing, perhaps unconsciously, some degree of prejudice. The usual method of showing subject is not by quoting a word apart from its context, but by simple statement, such as: Smith's Miocene . . . . Note that if the word Miocene in the statement is now enclosed in redundant quotation marks to say: Smith's "Miocene" . . . adding the marks does not further show the already shown subject, but modifies the word quoted by implying error or ridicule according to the general text and style of the author who quotes. Applying the marks to a word apart from its context misquotes Smith by conveying a meaning other than the original one. Thus, while the quoting of a word apart from its context to show subject is legitimate in neutral applications, it might be well for an opposing author to ask himself whether he is framing the word in that sense or to show personal disagreement or innuendo. It is safer for an opposing author to show subject by the more usual method of simple statement.

Another minor application of quotation marks is for an author to quote some word or phrase of his own to admit that his own usage is or was incorrect. For example, he may explain that rock allied to but not actually a basalt, granite, or sandstone, or a fossil resembling but not actually a particular form, will for convenience be referred to as such. Thereafter, when he refers to this rock or

[4] A quotation of more than a few lines is ofttimes preferably for clarity presented in distinctive type set apart from the text of the one who quotes, without using quotation marks. Omission within a quoted sentence is commonly indicated by three consecutive periods (or asterisks); omission between sentences by four periods including the punctuating one.

fossil in his paper, he may enclose the name used in quotation marks to show that in his opinion—in effect universal—his own usage is in error. Or he may quote some former name of his own to show admitted error. In both cases he is the sole judge; permission is unanimous. (Doubt may be shown by an interrogation mark; patent error by special use of quotation marks. Many authors confuse the two.)

Still another, minor, and in science dangerous usage is to frame in quotation marks a word, phrase, or name used by another person, for the purpose of suggesting that use of this word, phrase, or name involves patent error. The usage is not very common among scientists, though occasionally invoked, because these tend to be cautious about passing judgment as to what is agreed to be true or false. Where agreement as to error is unanimous the usage may be justifiable. But agreement is rarely unanimous. The danger lies in the implication that he who so uses the quotation marks not only knows what is true or false, but that he is speaking for others who are agreed. The usage is therefore in a sense stronger than a flat, purely personal assertion, and less excusable if the implied agreement does not exist. There are many words—considered, supposed, held, believed, thought, viewed, interpreted, inferred, and so on—which can be combined with an expression of disagreement to indicate supposed error in a more accurate and safe manner.

A mild cousin of the foregoing usage is to show by quotation marks lay or informal custom, to emphasize that this is not scientific or formal custom, commonly preceded by the word *so-called* or equivalent introduction. This particular variant tends to be more or less harmless because the application is usually clarifying and neutral. To attain this status, however, there must be no intent to ridicule. Taking pedantic exception to informal custom can be overdone; though technical wording is ofttimes the more precise one, a simple expression of laymen or fellow workers is not necessarily inferior to more complicated expression if the two have the same meaning. Where an informal name or description is preceded by the word *so-called* or equivalent introduction quotation marks are commonly superfluous.

Usages thus far outlined tend to be in at least some applications legitimate. The writer now turns to other usages that may be more questionable.

Some authors have used quotation marks, rather than an interrogation mark, to show doubt. The interrogation mark is obviously the proper symbol by which to show doubt. Authors who use quotation marks to express doubt risk having such usage interpreted by a reader as any of several other usages ranging down to ridicule and scorn, which latter two hover near or shadow most improper or questionable usages. Before an author spoils his page with close-spaced garish quotation marks—susceptible of being interpreted as indicating patent error or innuendo—solely to show doubt, he might well consider showing this by neat, unmistakable interrogation marks, the proper symbol by which to show doubt.

Of late years there has been the occasional practice in science, as yet not widespread, of framing by quotation marks any concept, usually as a lifted key word

or phrase, that an author personally disagrees with. In extreme cases a printed page may be speckled with such occurrences as an author registers his personal distaste. To hold up an opposing concept to specially unfavorable notice by isolating its key word or phrase between quotation marks rather than simply stating disagreement ofttimes involves, in some degree, an element of ridicule. The circumstance that quotation marks are more widely applied to a single lifted word or phrase to indicate patent error tends to give an author who uses them in the rarer way to express personal disagreement a temporary advantage, for the average reader may interpret the marks as meaning agreed error, not personal disagreement. The advantage so gained may, however, be regarded by some readers as a form of begging the question. Most authors who use quotation marks to express personal disagreement are apparently sincere, zealous workers who do not adequately realize the obligation in science to use the marks in ways which will not be misinterpreted. Personal disagreement is perhaps more effectively presented by evidence in combination with a plain statement of disagreement than by framing an isolated word or phrase in quotation marks.

Usage of quotation marks to express personal disagreement has many variations. Complex variants, where a compound expression is framed to express part disagreement, may involve so intricate a mixture of original and added meanings as to defy analysis. In its simple extremes, however, the usage ranges from quoting a single word for the conscious purpose of expressing personal disagreement, to where the word is quoted to include, unconsciously, that purpose, under the misconception that only subject is being shown. All variants have in common the feature that the meaning of the person quoted is changed. As previously mentioned: Smith's Miocene (complete, just), and Smith's "Miocene" (redundant, misquote, begging the question), have very different meanings. Even if the age be Cambrian it is still *Smith's* Miocene, without quotation marks unless he used them, and an opposing author is required to show another age through evidence, not by misquoting Smith. If Smith has admitted error, then: Smith's former Miocene.

Some authors use the quotation mark indiscriminately to express patent error or personal disagreement. Others, indiscriminately for error, disagreement, or doubt. Still others occasionally isolate and frame by the mark almost any noun, adjective, or verb, without discernible reason. The practice tends to in some way distort or confuse the original meaning. In the opinion of the present writer, to isolate and frame a word in such a way as to change its meaning does not constitute an adequate quote, but is a form of misquotation.

This brief outline is written because it has been observed that some young students appear not to realize dangers involved when using quotation marks; that these marks, which can be used and interpreted over a vast range of meanings, are dynamite; that some older geologists come to dread selecting abstracts to quote under even the basic, most legitimate usage, because of the ofttimes extreme difficulty of avoiding misquotation through omission when enclosing an

abstract in quotation marks. The marks are not a symbol to be lightly or carelessly inserted. They may reflect quotation to show information, subject, admitted error, patent error, lay custom, informal custom, personal disagreement, or ridicule, either separately or in combinations over a wide and sensitive range of shades. Or be improperly and confusingly substituted for the interrogation mark, with modifying shades of one or more of the foregoing meanings.

Most professional workers of the writer's acquaintance appear to be in substantial agreement regarding the basic use of the quotation mark. But few have agreed on minor usages. Let us take patent error as an example—does this follow from universal agreement? Almost universal? Substantial? Majority? An author who quotes an isolated word to express personal disagreement reflects in a sense an end phase of the foregoing, for error may be patent to him if to no one else. There is thus no assurance when we lift a word from its context and frame it in quotation marks to express some personal idiosyncrasy that numerous readers with different idiosyncrasies will interpret the quoted word as we meant it. Many authors might be aghast if they knew what implications some readers were reading into a word thoughtlessly isolated by quotation marks on the spur of the moment. Once we step outside the time-honored basic usage in science we step into kaleidoscopic interpretations, and may unthinkingly twist the plain statement of some plodding fellow worker.

That various readers will disagree with details herein seems inevitable. The writer disclaims any idea of being final on the complicated subject, or that his outline more than approximates general usage. His purpose is to call attention to the danger, in science, when the quotation mark is used in meanings other than its basic one, and the probable advisability of using it with caution in other than its basic meaning.

The writer feels that choice in customary usages of the quotation mark is a matter for each individual author to decide. The advice of experienced friends, teachers, and editors is ofttimes invaluable, but it is felt that except where there is the most obvious misquotation of another person an author is the final judge. Uniformity, clarity, and other attributes may be desirable, but are considered negligible compared to unfettered opinion in science.

SUMMARY

The quotation mark has diverse lay usages, involving a vast range of meanings and innuendos. In science generally preferred usages may be more restricted, owing to emphasis on accuracy, evidence, and apparent fact. Some usages of the quotation mark are summarized:

1. The basic and always legitimate usage of the quotation mark in science is at the beginning and at the end of a direct quotation so chosen as to reflect, as faithfully as possible, a datum, data, idea, or ideas, of the person quoted. Wholly legitimate variations of the basic usage that exist are confined to applications which do not distort or otherwise change the meaning of words quoted.

2. A single word or short phrase is sometimes lifted and quoted to show sub-

ject, instead of the usual practice of showing subject by plain statement. If such abbreviated usage deviates in the slightest from neutrality, shades of one or more of the following meanings tend to be included.

3. A minor and dangerous usage of quotation marks is to enclose a word, phrase, or name used (a) by the author, or (b) by another person, for the purpose of suggesting that use of this word, phrase, or name involves patent error. There are at least these two varieties:

(a) By an author to admit error in some datum, classification, or idea of his own. Since he is the sole judge, opinion and permission are unanimous. There may be little direct objection to the particular usage, but there are indirect disadvantages through association with some other usages. (Doubt is shown by the interrogation mark.)

(b) By an author for the purpose of suggesting that some datum, classification, or idea put forth by another person involves patent error. This usage, perhaps legitimate if universally agreed error is involved, in practice tends to be dangerous because the author using it in effect passes final judgment on a question of truth or error, and because the implied agreement may not exist.

4. Quotation marks are sometimes used to set off lay or informal custom to emphasize that this is not scientific or formal custom. The usage tends to be harmless where the application is neutral, but undesirable if inferiority is implied. When informal custom is preceded by the word *so-called* or equivalent introduction quotation marks are commonly superfluous.

5. Another minor, as yet rare usage of quotation marks in science though widespread in lay practice, is to frame by these marks any concept, usually as a lifted key word or phrase, that an author personally disagrees with. The practice may or may not involve an element of ridicule or scorn; it is difficult to avoid these implications. Since the average reader who sees a single word or phrase lifted and framed by quotation marks tends to have in mind the wider usage to indicate agreed error, an author who uses the marks to express personal disagreement may gain temporary advantage through association. There are reasons to believe, however, that an ultimately more effective procedure may be to present the evidence together with a plain statement of disagreement.

CONCLUSION

When using the quotation mark the most important thing is, surely, not to misquote. Any usage, even the quoting of a single word, can be defended *if* the meaning of the person quoted is not changed. We do not misquote intentionally. We misquote unintentionally; through omission; through misunderstanding; through blinding zeal to correct error and establish truth—as we see these. It is obvious that, when extracting, the shorter the quote the greater the average danger of misquotation, and the greater the care necessary to avoid this. Also, the more strongly we feel about a subject the more care is required when quoting opposing views.

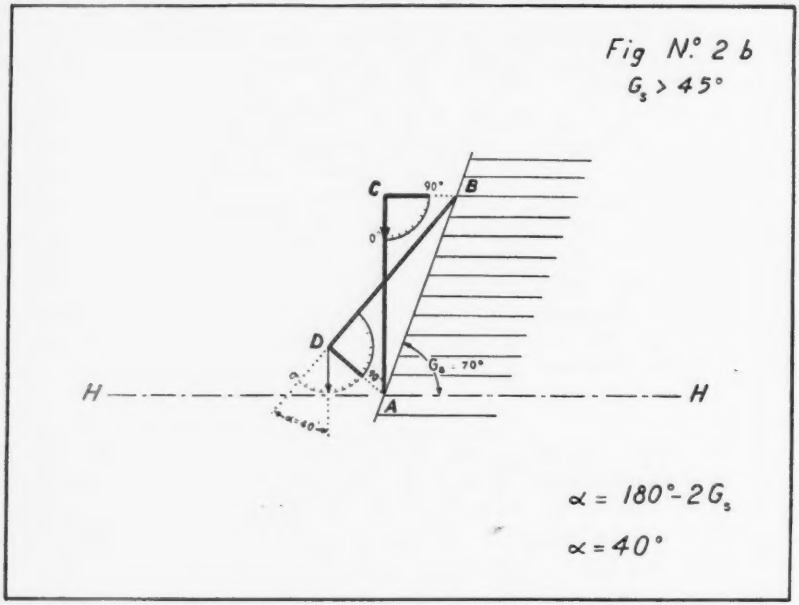
Except in its basic meaning to delimit a direct quote the quotation mark is

usually optional, for by sentence construction other meanings such as subject, admitted error, patent error, lay custom, informal custom, or personal disagreement can be shown at least as effectively without it, and doubt is shown much more clearly by the interrogation mark. Owing to dangers and disadvantages, direct or indirect, attending nearly all usages of the quotation mark other than the basic one, it might be advisable, in science, to use the mark chiefly in its basic meaning, and only with caution in other meanings.

"JACOB STAFF" AND MEASUREMENTS OF STRATIGRAPHIC SEQUENCES—A CORRECTION[1]

J. A. BROGGI[2]
Lima, Peru

In the geological note, " 'Jacob Staff' and Measurements of Stratigraphic Sequences," in May, 1946, *Bulletin*, Vol. 30, No. 5, page 719, Figure No. 2 b was erroneously used. The correct Figure 2 b is here shown.



[1] Correction received, September 30, 1946.

[2] Director, Instituto Geologico del Perú; secretary, Sociedad Geologico del Perú.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 11 (NOVEMBER, 1946), PP. 1935-1954

RESEARCH

PROGRESS REPORT ON A.P.I. RESEARCH PROJECT 43, "THE TRANSFORMATION OF ORGANIC MATERIAL INTO PETROLEUM"[1]

G. M. KNEBEL[2]

ABSTRACT

A brief history of A.P.I. Research Project 43 is presented, showing its origin as an outgrowth of the Parker Trask project (No. 4). The so-called "Geological Fence," prepared as a guide to the fundamental studies of Project 43, is briefly outlined.

Progress and results obtained by the three coordinated sub-projects (43-a, b, and c) are summarized, and comments on each are made, pointing to the more important unsolved problems toward the solution of which the future research work of Project 43 will be largely directed.

Theories of the origin of oil are discussed, and the need for other research work on the origin of oil, in addition to A.P.I. Project 43, is emphasized.

INTRODUCTION

Petroleum geologists have devoted more attention to the origin of oil than to any other geological question. Geological literature is rich in material on this subject. Workers as far back as 1864 began to speculate on the origin of this complex material. Now, with over 80 years of practical experience behind us, we know how to locate accumulations but have not solved the origin problem. Its solution will enable us to locate oil fields with greater certainty. For 14 years, the A.P.I. has been conducting research work on the origin of oil. Progress is being made but the field to be covered is so extensive that additional research projects on this subject should be undertaken.

SHORT HISTORY OF PROJECT 43

American Petroleum Institute Research Project 43, entitled "Transformation of Organic Material into Petroleum," was an outgrowth of and the successor to A.P.I. Project 4, "Origin and Environment of Source Sediments of Petroleum," which terminated on June 30, 1941, after about 10 years of brilliant work by Dr. Parker D. Trask and his co-workers.

The monumental work of Parker Trask and his co-workers included the collection and study of more than 35,000 samples of recent bottom sediments from marine and estuarine localities in many parts of the world. The results of this work have been published and widely read, and are familiar to all petroleum geologists.

The methods of attack employed in the Parker Trask project were empirical. Interesting as were the results, and useful to geologists as they may prove, this project was concluded because of a widespread feeling among petroleum geologists that a new approach to the problem was needed, involving research of fundamental nature.

Decision to wind up the work of Project 4, and to attempt the formulation of a new project on the origin of petroleum were made by the Advisory Committee of A.P.I. Research Project 4 at Chicago, April 12, 1940, under the chairmanship of Dr. K. C. Heald. At this meeting, preliminary research proposals from Dr. Revelle of the Scripps Institution

[1] Read before the Association at Chicago, April 4, 1946. Sponsored and financed by the American Petroleum Institute. Manuscript received, March 23, 1946.

[2] Head of the exploration division, producing department, Standard Oil Company (New Jersey). The writer is indebted to Dr. K. C. Heald, chairman of the Editorial Reviewing Committee of A.P.I. Project 43, for much of the material included covering the progress and results of the work at the three institutions. Dr. Bela Hubbard, geological co-director of A.P.I. Project 43, has been of great assistance in preparing this report because of his close contact with the project.

of Oceanography and from Dr. Berl of the Carnegie Institute of Technology were presented and discussed briefly. The committee adjourned without making any decision, but with the agreement that individual members would consult with other geologists; would study carefully the two preliminary proposals; and would develop the possibility of obtaining additional research proposals.

After 7 months of correspondence and discussion, the Project 4 Committee met again at Chicago, November 11, 1940. Dr. Heald relinquished the chairmanship, and Mr. B. B. Cox was elected chairman, and given the responsibility of developing new research proposals on the origin of petroleum. Scope and objectives of the new research work were discussed, and nine different titles were suggested for the new project. From these, the title "Transformation of Organic Material into Petroleum" (proposed by Mr. Cox) was subsequently officially adopted. The committee felt that, although the principal line of attack in the new research project should be chemical, the program should also include bio-chemical and bacteriological studies, as well as radioactivity studies.

At the "Origin of Petroleum" symposium, A.A.P.G. meeting, Houston, April 5, 1941, Mr. Cox presented a paper entitled, "Observations Bearing on a Laboratory Study of the Transformation of Organic Matter into Petroleum." This paper was intended as a "Geological Fence" for guidance of the proposed new A.P.I. research project. Copies of this "fence" were later distributed to many of the petroleum geologists, chemists, physicists, and biologists of the country, with requests for criticisms and comment. Later on, revised editions of this "fence" were circulated, which incorporated thoughts and suggestions received from scientists. The "fence," therefore, eventually became a fair cross section of scientific opinion on the subject.

During the A.A.P.G. Houston meeting in April, 1941, the A.P.I. Advisory Committee on Project 4 met, and voted unanimously in favor of a new A.P.I. research project with the previously suggested title, and designed to follow several lines of approach, including chemical, bacteriological, and radioactivity. Reports of investigation by Committee members listed eight universities having laboratories and research staffs suitable for undertaking such a project.

During the summer of 1941, committee members contacted these universities as well as others. As the result of these contacts, more or less definite research proposals were received from six institutions: Pennsylvania State College, Massachusetts Institute of Technology, Johns Hopkins University, Princeton University, University of California, and Scripps Institution of Oceanography. Proposals from the University of Chicago and Harvard University were also received, but too late for consideration with the others.

Copies of the six research proposals, together with revised copies of the "Geological Fence" were sent to Mr. A. I. Levorsen, chairman, and members of the A.A.P.G. Research Committee, as well as to a large number of petroleum geologists, research workers, teachers of geology and chemistry, in all parts of the country.

From all these persons, many valuable suggestions and criticisms of the proposals were received. In addition to these activities, A.P.I. committee members visited the six universities submitting research proposals; inspected the laboratory facilities; and discussed the problem with research staff members.

On November 2, 1941, Mr. Cox's A.P.I. Committee met in San Francisco, just prior to the Annual A.P.I. sessions. The meeting was attended by many interested petroleum geologists, chemists, and other scientists. Mr. Levorsen reported the recommendations of the A.A.P.G. Research Committee, which favored the carrying out by A.P.I. of research work along the general lines of the six detailed proposals. Two days later, Mr. Cox's committee met again, and drew up the following recommendations, which were subsequently formally presented to the A.P.I. Advisory Committee on Fundamental Research on the Occurrence and Recovery of Petroleum.

1. That a new A.P.I. Research Project be initiated under the title, "Transformation of Organic Material into Petroleum"
2. That the research work be divided among the three research institutions whose proposals had received the widest approval among petroleum geologists and petroleum chemists
3. That the first year's budget, fiscal year beginning July 1, 1942, be set at $17,800 and allocated as follows

The Scripps Institution of Oceanography	$6,000
(a) Bacteriological phases of the work, and collecting of marine bottom sediments	
(b) The Pennsylvania State College	$8,600
Chemical, physico-chemical, and bacteriological phases of work	
(c) Massachusetts Institute of Technology	$3,200
Radioactivity studies	

The foregoing recommendation was duly approved by the A.P.I. Advisory Committee on Fundamental Research, and passed on to the A.P.I. Research Committee of the Board of Directors for action the following spring.

During the months following the November meeting in San Francisco, Mr. Cox's committee was active in making tentative plans for the composition of the new committee, coordination of the new research work, and other details. Meetings of the committee were held on January 17 and 18, 1942, at State College, Pennsylvania, and again on February 8 in New York City.

By March, 1942, it became known that the members of the A.P.I. Research Committee of the Board of Directors were divided on the question of approving a new research project. At the behest of Mr. Cox, interested petroleum geologists wrote to A.P.I. board members urging their approval, and stressing the need for the new research project. Among the factors adversely affecting the A.P.I. board action was the fact that the country was engaged in World War II. Some board members felt that war time did not afford a favorable occasion in which to launch a new long-range research project. However, pressure exerted by petroleum geologists finally won out, and the A.P.I. Board of Directors, late in the spring of 1942, approved the new research project, contingent upon raising by subscription of the necessary funds. The funds were subscribed in due course, and the new project, tentatively known as "Project A," was launched. One of the events during these critical months in the Spring of 1942, which doubtless did much to win over the A.P.I. directors, was the resolution of indorsement by the A.A.P.G. at its Denver meeting in April, which read as follows.

> The American Association of Petroleum Geologists endorses the geologic project known as "The Transformation of Organic Material into Petroleum" and urges that it be included in the Research Program of the American Petroleum Institute. This Association, which includes in its membership most of the geologists who are the oil-finders of the industry, believes that the increasing difficulty experienced in discovering new fields makes it vital to furnish the geologists with all the help modern science can render, and that without new knowledge to apply to the search for oil, that search will steadily decline in effectiveness. The proposed project, formulated after careful consideration of the types of new knowledge most likely to increase success in the search for oil, is urged as a measure of security and economy.

Copies of this resolution went to the president, board members, and members of principal research committees of the A.P.I., as well as to representatives of subscribers to A.P.I. maintenance funds on research.

The necessary funds had been subscribed by the first week in June, 1942, and the new project was officially designated as A.P.I. Project 43. The project was divided into three sub-projects, as follows.

Project 43(a)—Director—Dr. C. E. ZoBell, Scripps Institution of Oceanography
Project 43(b)—Director—Dean F. C. Whitmore, Pennsylvania State College
Project 43(c)—Director—Prof. W. J. Mead, Massachusetts Institute of Technology

The first meeting of the Project 43 Advisory Committee, together with the three re-

search directors (or their representatives) was held at State College, Pennsylvania, on August 22 and 23, 1942. Since that occasion, the committee and research directors have met together at least once each year throughout the difficult war time years and up to the present. Due to his entrance into the military service, Mr. Cox relinquished his chairmanship, and Mr. G. M. Knebel was chosen to succeed him.[3] Under Mr. Knebel's chairmanship, the work and functions have expanded, to include three regional chairmen and their regional sub-committees, each delegated to keep in close contact with the research group in its respective region. In addition, a Chemical Sub-Committee has been organized, under chairmanship of Dr. W. E. Hanson of Mellon Institute, including in its membership eight leading petroleum chemists. The function of this Chemical Sub-Committee has been to follow the chemical aspects of the research work of Project 43, and to render such advice and assistance on analytical problems as may be possible.

From a budget of $17,800, for the initial fiscal year, 1942–43, the annual budget has increased to $36,000 for the year 1946–47. The total budgeted for the 5 years is $134,310.

SUMMARY OF THE "GEOLOGICAL FENCE"

A "Geological Fence"[4] was compiled by Mr. Cox to keep research workers from following leads that do not represent conditions which occur in the sedimentary environment. The main supports of the "fence" are called "posts" because of multiple occurrence while additional observations are considered as "stakes." The "posts" are the following.

Organic origin.—Most geologists believe that petroleum is of organic origin because of its association with sediments relatively high in organic matter. Optically active constituents, chlorophyll derivatives, and nitrogenous compounds are cited as evidence of organic origin because petroleum-like products formed in the laboratory from inorganic substances do not contain these substances.

Marine environment.—The vast majority of the world's oil fields are associated with marine sediments. The average organic content of recent marine sediments near shore is approximately 2.5 per cent and of ancient sediments 1.5 per cent. Organic content of more than 8 to 10 per cent has been reported from local areas. Trask did not find any statistical relationship between quantity of organic matter and the occurrence of petroleum. The presence of liquid hydrocarbons in recent marine sediments has not been definitely settled. However, if present, they amount to probably less than 1 per cent of the organic content of the sediment.

Temperature.—Temperatures of at least 113° C. (235° F.) have been recorded in the subsurface of petroliferous basins but in rare cases do they exceed the boiling point of water. Maximum temperatures for most basins have been more or less in the neighborhood of 100° C. The presence of porphyrins in petroleum indicates that the maximum temperature has been less than 200° C. Assuming an average temperature gradient of 1°C. per 100 feet, an average surface temperature of 15°C., and an overburden of 5,000 feet, oil could be formed at temperatures near 65°C. Temperatures in oil fields are commonly higher than temperatures in adjacent synclinal areas suggesting some type of exothermic reaction.

Pressure.—Since petroleum is found in basins which have had a stratigraphic thickness of about 5,000 feet, oil apparently occurs when hydrostatic pressures are as low as 2,000 parts per square inch or less, and weight of overburden 5,000 parts per square inch. (Oil apparently forms with an overburden of 3,000 feet or less as witnessed by the many tar deposits of the world.)

Time.—Petroleum occurs in sediments of all ages from the Cambrian to the Pliocene,

[3] Mr. T. V. Moore became chairman of this committee, January 21, 1946.

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inclusive. Unquestionably indigenous oil is not yet known from the Pleistocene, however, this formation has not been sufficiently prospected under the proper marine setting with sufficient cap to say that oil did not generate during this period.

The "stakes" of the "fence" cover observations on radioactivity, bacteria, catalysts, variations in composition and properties of petroleum, hydrocarbons formed by living plants, and maturation.

RESEARCH PROGRESS TO DATE OF PROJECT 43

In reviewing the progress and results of Project 43, the three sub-projects are best considered separately, since the lines of attack on the problem have been different and there has been relatively little duplication of effort.

PROJECT 43(a)—SCRIPPS INSTITUTION OF OCEANOGRAPHY
RESEARCH DIRECTOR—DR. C. E. ZOBELL

Original proposal.—In its original proposal to A.P.I., Scripps Institution of Oceanography undertook to investigate the part that might have been played by marine bacteria in the transformation of organic material into petroleum; to study the occurrence of hydrocarbons in ocean-bottom sediments; and to obtain cores of such ocean-bottom sediments for the studies at Scripps, and also to supply samples to the other two research groups. Scripps also undertook to search for and to study bacteria found in oil-well brines, crude oils, rock cores from bore holes, and other geological sources. Tarry and oily materials separated from marine muds were to be identified as to chemical nature and their alterations due to bacterial action studied. Marine bacteria were to be isolated and identified, and their abilities to transform known organic compounds studied. Studies were planned on the effects of marine bacteria on the hydrogen-ion concentration (pH) and the oxidation reduction potential (E_h) of marine bottom sediments. Special attempts were to be made to develop methods to determine the E_h of petroliferous materials.

Progress of Project 43(a).—In spite of severe war-time handicaps and personnel shortage, Dr. ZoBell and his associates have obtained a large volume of data, most of which are new and of great potential value. The collecting of ocean-bottom cores, as planned in the original proposal, has so far been deferred because the Scripps research vessel has been in use during the war by the U. S. Navy. However, Dr. ZoBell has been able to obtain some bottom samples, while others, obtained before the war, afforded bacterial cultures which have been utilized on this project during the past three years. Other samples, supplied to Scripps by interested oil companies and others, have included well cores, oil-well brines, tar sands, asphalt, oil sands, petroleum, and pure organic compounds. These materials have afforded extremely interesting research results in spite of the lack of fresh supplies of marine bottom sediments.

Results to date—Project 43(a).—Results thus far obtained on this project are too numerous to describe in a brief report. Many of these results are apparently of great potential significance, and need following up with future investigations. The following are considered outstanding among the results obtained by Dr. ZoBell and his associates in Project 43(a) during some three and one-half years of work.

1. Biochemically diverse bacteria have been found in both recent and ancient marine sediments. Those obtained from well cores and bore holes may have been introduced during drilling, but nevertheless are able, in some instances, to multiply and thrive in these ancient rocks. In one instance, bacteria from a Louisiana salt dome cap rock at 1,560-feet proved to be of a type never previously found in the earth's surface or in recent marine sediments. These may have been indigenous to the cap rock in which they were discovered. The existence of living bacteria at depths is not definitely proved and if they do occur, they are less abundant than nearer the surface.
2. Bacteria have been found in abundance in fluids from oil wells coming from depths of several thousand feet.

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2. Bacteria have been found in abundance in fluids from oil wells coming from depths of several thousand feet.

3. Some bacteria can grow at temperatures as low as 0°C.; others at temperatures as high as 85°C.
4. Some bacteria are not injured by hydrostatic pressures up to 150,000 p.s.i.
5. Certain bacteria thrive in fluids of low salinity; others in brines with much higher salinity than ocean waters.
6. Bacteria are most abundant at the mud-water contact of present ocean-bottom deposits and decrease rapidly down to 2 feet where their number is small compared with the contact layer. The effect of bacterial enzymes at depths remains to be studied.
7. Most bacteria studied have been facultative anaerobes. They will attack all kinds of organic materials which have been tried.
8. In the laboratory, selected bacteria under reducing conditions will modify certain organic compounds in the direction of making them more petroleum-like. For example, certain sulphate-reducing bacteria, utilizing various organic acids, have produced oil-like extracts, similar to hydrocarbons.
9. In the laboratory, it has been demonstrated that anaerobic fermentation of organic matter can liberate hydrogen or induce the direct transfer of hydrogen from one compound to another.
10. A rapid and satisfactory method for determining the E_h of recent sediments has been perfected and apparatus for this made and put into operation. This technique promises to be of value in the identification of potential petroleum source beds. It also may lead us to a better understanding of the bacterial and chemical processes which differentiate source sediments from non-source sediments.
11. Some evidence has been obtained to indicate that the E_h of a sediment has a pronounced effect on diagenesis. Further work on the E_h of sediments promises to yield important additions to our knowledge of diagenesis, as well as the origin of petroleum.
12. Certain sulphate-reducing bacteria have been found in the laboratory to be instrumental in liberating oil from oil-bearing sedimentary rocks.
    (a) Some types of sulphate reducers dissolve carbonates by carbonic acid and organic acids thus releasing oil from a petroliferous limestone. The resultant release of carbon dioxide would also tend to lower the viscosity of the "liberated" oil.
    (b) Other types of sulphate reducers produce detergents, and these detergents release oil adsorbed on the sand-grain surfaces.
    (c) Still other types of bacteria, known as "thigmotactic" bacteria, have the tendency to attach themselves to the solid rock surfaces in a sediment, thereby crowding off the adsorbed oil films.
    (d) Another group of anaerobic bacteria, known as "lipoclastic" anaerobes, have been shown by laboratory experiments, to be capable of splitting long-chain hydrocarbon molecules into shorter-chain molecules. Certain heavy crude oils, subjected to the action of these bacteria, have shown a slow but definite increase in A.P.I. gravity and decrease in viscosity.
13. Laboratory experiments have demonstrated that certain crude oils have ingredients exerting a bacteriostatic effect on all or many bacteria. There are at least 50 known species of bacteria representing more than 12 different genera which under suitable environments are known to utilize one or more kinds of hydrocarbons. The chief difficulty in our origin of oil problem is not to account for sufficient organic material to supply the known petroleum reserves, but rather to explain how the organic materials and the petroleum hydrocarbons in the earth have survived destruction by all the known species of predatory hydrocarbon-consuming bacteria. One explanation may lie in the presence of bacteriostatic substances in the sediments, in the petroleum, in the associated brines, or in all three. Among the known bacteriostatic substances are vanadium, copper, nickel, and some other metals. Burial is probably the most important preservative as bacteria can not destroy all organic matter, and as mentioned under No. 6, the bacteria decrease greatly in numbers with depth.
14. It has been shown that hydrocarbon-oxidizing aerobic bacteria are abundant and very active in altering and in destroying hydrocarbons. This may possibly explain failure to detect hydrocarbons in ocean-bottom sediments, samples of which have been exposed to the air and to action of these bacteria prior to laboratory analysis.

Comments and conclusions—Project 43(a).—It may be stated conservatively that the 3½ years work of Project 43(a) by Dr. ZoBell and his associates has very materially increased our knowledge of the behavior of bacteria with respect to organic compounds and to sediments. It will be evident, however, from our brief review of the outstanding results of this work, that much remains to be done before we can know just how important bacteria have been in the transformation of organic materials, buried in the earth, into

petroleum hydrocarbons. Our knowledge thus far is limited largely to the results obtained in the laboratory. Although the laboratory conditions have invariably been within our "Geologic Fence," we still can not exactly reproduce the complicated sets of conditions which must obtain down in the earth's crust.

It is still impossible to state categorically that bacteria in the sediments play an essential part in the transformation of the organic matter to petroleum. We are far closer today to a solution of this question than we were 4 years ago. Nevertheless, definite proof is still lacking. Bacteria do condition organic matter and create a favorable E_h and pH environment.

Proof that hydrocarbons identical with those of petroleum exist in recent ocean-bottom sediments is still largely lacking. Techniques must be devised to collect such samples and bring them to the laboratory for analysis in such manner that their organic contents will remain unchanged by contamination, oxidation, or other extraneous factors.

More conclusive evidence is needed on the occurrence of bacteria in ancient sediments and in reservoir fluids. Here again, new techniques are urgently required to minimize contamination and alteration of cores and fluid samples during and subsequent to sampling in bore holes.

Laboratory experiments must be repeated, providing conditions of environment, temperature, and pressure more closely approximating those occurring in the earth's crust within the depth ranges of known oil occurrence.

Additional laboratory work, involving improved analytical methods, are needed to prove that certain anaerobic bacteria are able to decarboxylate and deaminize organic compounds and produce hydrocarbons from these compounds.

The laboratory observation that certain bacteria will liberate hydrogen or transfer hydrogen from one type of organic compound to another calls for a great deal of additional careful research work. The possibility that hydrogenation may be an important factor in converting organic material in the earth to petroleum has been widely discussed in past years. A strong argument against this theory of natural hydrogenation has been the apparent absence of free hydrogen in the reservoir formations and in natural gas. In recent months, mass spectrograph analyses have indicated small percentages of hydrogen in natural gas. If the results of these analyses are confirmed, its existence in the earth in a free state may be much more widespread than we have realized. Also, many chemists think that the nascent hydrogen produced recombines almost immediately. The part played by bacteria in the liberation and chemical transfer of hydrogen in sediments requires a great deal of additional research work.

Laboratory studies involving measurements of the pH and E_h of sediments suggest that comparatively strong reducing conditions obtain in petroliferous formations and in organic shales corresponding with our notions of possible source beds. Many of the world's silled basins, which are high in organic content (Black Sea, Pleistocene Fiords, Gulf of California, and Tahoe Basin N.E.I.), have a strong reducing environment. Additional proof is needed to show that reducing conditions promote the formation and preservation of hydrocarbons. The role of bacteria in this relationship requires further study.

Project 43(a) has, therefore, not solved most of our problems, and has raised new ones requiring solution. However, the progress which has been made appears to have been very considerable, and by all indications, in the directions we should continue to follow.

PROJECT 43(b)—PENNSYLVANIA STATE COLLEGE
RESEARCH DIRECTOR—DEAN F. C. WHITMORE

Original proposal.—The original proposal by Pennsylvania State College was to attack the problem of "Transformation of Organic Material into Petroleum" in the fields of chemistry, bacteriology, physical chemistry, and physics.

In the chemical field, it was planned to study the transformation of selected pure organic compounds into hydrocarbons of the type found in petroleum, under controlled conditions of temperature, pressure, and catalysis. From simple individual compounds, the work was to advance to the study of more complex compounds and mixtures, such as occur in nature. Where transformations yielded mixtures, the individual components were to be separated and identified. It was also planned, if necessary, to synthesize compounds of definite structure for comparison with materials obtained from the experiments on transformation.

In the bacteriological field, it was proposed to attempt the isolation of bacteria from uncontaminated petroleum, and to study characteristics of any such bacteria found, and identify the species. It was proposed to study the enzymatic action of bacteria isolated from petroleum and from sediments, employing proteins, carbohydrates, fats, hydrocarbons, and other organic compounds. Known and new species of bacteria were to be studied for their ability to produce hydrocarbons. The action of bacteria on petroleum and its constituents was to be studied. Also to be studied was the action of various bacteria on materials developed from the chemical studies. It was recognized that not all of these studies could be covered under the project, and that a selection would be made under guidance of the Research Advisory Committee based on the requirements of other phases of the work.

In the field of physics, no definite lines of attack were proposed, but the facilities of Pennsylvania State College in this field were to be made available if and when needed.

In the field of physical chemistry, it was proposed to study the heat capacities and heats of combustion of typical hydrocarbons found in petroleum and the pure compounds found in possible source materials. From these studies, calculations would be made of the conditions permitting transformation of the oxygen-bearing compounds into hydrocarbons.

Progress of Project 43(b).—War-time conditions interfered seriously with progress of Project 43(b). The research director, Dean F. C. Whitmore, soon after initiation of the project, became occupied almost exclusively in other projects connected directly with the war effort, and was able to devote very little time to the A.P.I. research. The Bacteriology Department soon became occupied with penicillin research, in which they made outstanding contributions to the war effort. In spite of their higher priority war work, they nevertheless were able to carry on a considerable amount of bacteriological work for Project 43(b), which resulted in very material contributions to the solution of our problems.

In the chemical field, Dr. T. S. Oakwood carried on despite handicaps due to lack of personnel. In the absence of Dean Whitmore, he acted as research director, continued in teaching activity, and was compelled to do some of the laboratory work himself, ably assisted by Dr. H. D. Zook.

Much of the time of the chemists in Project 43(b) was taken up in making analyses of the products of materials which had been subjected to radioactive bombardments at Massachusetts Institute of Technology under Project 43(c). This work involved a serious analytical problem, as the irradiated products supplied to Pennsylvania State College were usually in very minute quantities and consisted in very complex mixtures. A microfractionating apparatus had to be designed and built by Dr. Oakwood and Dr. Zook, and new techniques for micro-analysis had to be devised. All this preliminary work had to be done under the severe handicap of shortages in personnel and materials. The group of Pennsylvania State College is to be commended for the real progress they have made under these war-time handicaps.

Results to date—Project 43(b). Physico-chemical results.—No work in this field has been done, due probably to war-time conditions which prevailed.

Chemical results.—The most important results which have been achieved may be enumerated as follows.

1. Analytical methods were conceived, apparatus devised, constructed, tested, and put into operation in the analysis of bombardment samples supplied by Project 43(c). The methods and apparatus for this work had to be invented, as there was little or no published information on the subject to serve as a guide.
2. Methods were devised for extracting organic compounds from marine kelp, fresh-water algae, for isolation of low molecular-weight hydrocarbons from plants, and for isolation of ethane from bacterial fermentation gases.
3. Between 30 and 40 analyses were made of small samples of gases and liquids, which were the cyclotron and alpha-particle bombardment products supplied by Project 43(c). Although Dr. Oakwood's staff was unable to handle all the Project 43(c) samples requiring analysis, their assistance nevertheless constituted an important contribution to the radioactivity studies of Project 43(c).
4. Analyses of fresh-water algae revealed the presence of ergosterol. This discovery led to a study of various crude oils in the attempt to demonstrate the presence of sterols. This work is still in progress.
5. The presence of hydrocarbons as well as alcohols and organic acids was demonstrated in kelp, fresh-water algae, and bottom sediments of fresh-water pools. The latter discovery demonstrates that the hydrocarbons in recent sediments are not entirely or readily destroyed by bacteria.
6. At least one normal paraffine wax compound was isolated from the cell tissues of marine bacteria.
7. Hydrocarbon oils were isolated from oil which was a by-product of paper-pulp manufacture.
8. Hydrocarbon oils were isolated from penicillin mold.
9. Evidence was obtained that hydrocarbons from fresh-water algae and from pine trees contain approximately one ring per molecule, with no evidence of olefinic unsaturation.
10. It was demonstrated that hydrocarbons extracted from bacteria, from algae, and from kelp exhibit optical activity comparable in magnitude and sign with optical activity of the optically active fractions of petroleums. It was further determined that the optically active constituents of petroleums are limited to those fractions having a molecular weight of around 400, or in the molecular weight range of the sterols. Optically active extracts from marine and fresh-water plants have approximately the same molecular-weight range.

Bacteriological results.—The most important results obtained by the Bacteriology Staff, under supervision of Drs. M. A. Farrell and R. W. Stone, were the following.

1. Methods were developed for growing marine bacteria in large quantities. Bacteria were supplied by Project 43(a) as base stock.
2. It was determined which species of the marine bacteria furnished by Project 43(a) could be produced most abundantly under controlled conditions.
3. More than 10,000 grams of moist bacterial cells were furnished the Chemical Department for analysis. This is by far the largest quantity of bacterial cells ever amassed.
4. Collected asceptically samples of oil, brine, and oil sand from the "oil mine" in Venango County, Pennsylvania, and examined for indigenous bacteria. Bacteria were found in materials which had been exposed to air, but no bacteria were found from the centers of chunks of oil sand.
5. Experiments were made with bacteria to determine their ability to utilize methyl-acetic, propionic, lactic, and benzoic acids. It was found that these bacteria would not utilize these organic acids as long as 12 per cent or more of other nutrients were present. Under certain controlled conditions, the bacteria converted lactic acid to acetic acid.
6. Attempts were made to "train" bacteria to attack certain organic compounds in the absence of oxygen.
7. Well controlled experiments failed to indicate that bacteria will de-carboxylate organic acids of low molecular weight to the corresponding alcohols or hydrocarbons. These results appear to be at variance with those of similar experiments by Project 43(a), and more work along these lines is required.

Comments and conclusions—Project 43(b).—Many of the originally proposed lines of attack were not started, due to war conditions. Effort was concentrated on certain limited and obtainable objectives, and these were carried through to a conclusion. Under the difficult conditions of work during the past 3½ years, the Pennsylvania State College research workers are to be commended for the very material contribution they have made to our knowledge of the natural occurrence of hydrocarbons in plants and sediments, and of the role of bacteria in relationship to these hydrocarbons and other organic compounds.

It will be noted from the research results which have just been enumerated that these results are beginning to point in a rather definite direction. It is becoming evident that saturated hydrocarbons of the kinds found in petroleum occur abundantly in nature, both in land and marine plants. It is further becoming evident that these hydrocarbons are not easily destroyed under conditions destructive to many other types of organic compounds. As the title of Research Project 43 implies, our thinking on the origin of petroleum has been pretty much along the lines of chemical transformation. Organic matter, buried in sediments, is chemically transformed, the end product being petroleum. The research workers at Pennsylvania State College have departed somewhat from this mental approach, and have formulated as a working hypothesis the proposition that the generation of petroleum in the earth is very largely a process of selection and concentration of hydrocarbons originally synthesized by the metabolism of marine (or even terrestrial) plants.

This hypothesis is just as good as any that have been advanced to explain the origin of oil. The different plants and animals which contributed the hydrocarbons would naturally produce a material highly complex and variable in composition. It is estimated[5] that the annual photosynthesis occurring in the sea would account for 12 million tons (80,000,000 barrels) of hydrocarbon material. It is only necessary to save .01 per cent of these hydrocarbons over a period of 100 million years to account for the expected world's resources of hydrocarbons in commercial pools.

Projects 43(a) and 43(c), on the other hand, are proceeding under the alternative working hypothesis that the petroleum hydrocarbons, or most of them, originated by chemical reactions in the earth's crust from other chemical compounds, during the process of transformation of organic matter to petroleum. Both working hypotheses may eventually be proved valid for some of the petroleum hydrocarbons. Although there would appear to be a conflict in viewpoints between Project 43(b) and the others, this difference in approach is believed to be a healthy condition. The divergent approaches to the problem should insure against our traveling up a dead-end street.

PROJECT 43 (C)—MASSACHUSETTS INSTITUTE OF TECHNOLOGY
RESEARCH DIRECTOR—PROFESSOR W. J. MEAD

Original proposal.—Massachusetts Institute of Technology originally proposed a very comprehensive research program, but only a portion of this was accepted by A.P.I. The proposals which were accepted were as follows.

It was proposed to attempt to determine what part, if any, was played by radioactivity in the conversion of organic material into petroleum. The plan involved attempts to convert marine organic materials into petroleum by radiation of alpha particles (radon), by deuterons from the cyclotron, and by neutron bombardment. The radioactivity of marine organisms, organic materials, and sedimentary rocks was to be measured. The thorium-uranium ratios of organic sedimentary rocks were to be determined. Organic compounds were to be isolated from organic sediments of marine origin and efforts made to convert these organic compounds to petroleum by radioactive bombardments. Gases evolved during this radiation were to be measured and identified.

Progress of Project 43(c).—As with the other divisions of Project 43, the work at M.I.T. was handicapped by personnel shortage and by shortage of materials and equipment. Prof. W. J. Mead, research director, was unable to devote much time to the project, due to his war emergency work. In addition, the work was greatly slowed down due to a bottleneck in obtaining chemical analyses of the products of the radioactive bombardments. Bombardment samples could be and were produced at a much higher rate than they could be analyzed at Penn State College by the staff of Project 43(b). The project

[5] Gordon A. Riley, "The Carbon Metabolism and Photosynthetic Efficiency of the Earth as a Whole," *Amer. Scientist*, Vol. 32, No. 2 (April, 1944), p. 134.

at M.I.T. was located in the Physics Department, and no provisions were made for chemical analytical work to be done by the Organic Chemistry Department at M.I.T. A mass spectrometer was constructed by Dr. R. E. Honig to assist in removing the analytical bottleneck. Efforts were made to acquire an infra-red spectrometer. Finally the project was strengthened by additional A.P.I. funds to employ chemical research assistants and set up analytical apparatus to help handle the analytical work.

Dr. W. L. Whitehead, the geological co-director of the project, was engaged in war work during most of the war. He returned only in time to relieve Dr. Clark Goodman, who left the project temporarily to engage in some urgent war research.

Thus, the progress made at M.I.T. was under considerable difficulty. Drs. Goodman and Whitehead, who have actively guided the work of Project 43(c) are to be congratulated on having done well a difficult job.

Results to date—Project 43(c).—The results of the work at Massachusetts Institute of Technology have been as follows.

1. Equipment and apparatus has been constructed and techniques developed for analysis of the products of bombardments of gases, liquids, and solids.
2. Equipment and techniques have been developed for conducting bombardments under controlled elevated temperatures.
3. Preliminary steps have been taken in development of techniques and apparatus for conducting alpha-particle bombardments under controlled elevated temperatures and pressures paralleling conditions in the earth's crust.
4. Methane, butane, heptane, ammonia, acetic acid, athabaska tar oil, and palmitic acid have been bombarded in the cyclotron.
5. Methane, butane, pentane, n-pentane, hexane, ethyl ether, n-hexadecane, n-octacosane, athabaska tar oil, gilsonite, solid acetic acid, acetic acid (vapor), palmitic acid, lauric acid, calcium palmitate, cetyl palmitate, oleic acid, sebacic acid, and porphyrin complexes have been subjected to alpha-particle bombardment.
6. Several papers discussing the techniques, describing the equipment, and presenting the background and theory pertinent to the work of this project have been published.
7. Bombardments of gaseous hydrocarbons as a rule yielded gases and a liquid end product. Hydrogen was invariably found to be the chief gaseous product. Unsaturated gaseous hydrocarbons were found absent or only in traces in the products. The liquid products proved to be complex mixtures of unsaturated hydrocarbons, not found in petroleum.
8. Bombardments of liquid hydrocarbons yielded gases, liquids, and in some instances, a solid end product. The gases proved to be chiefly hydrogen with small amounts of hydrocarbon gases. The liquid products are believed to be unsaturated hydrocarbons. The solid products were not identified.
9. Experiments have indicated similar results for both alpha-particle and cyclotron bombardments.
10. Bombardments of organic acids resulted in decarboxylation and formation of carbon dioxide, methane, hydrogen, carbon monoxide, and possibly traces of hydrocarbon gases heavier than methane. In the case of palmitic acid, a liquid product was obtained, the physical properties of which were very close to those of n-pentadecane. Lauric acid yielded a small amount of liquid possessing physical properties close to those of undecane.
11. Bombardment of athabaska tar resulted in evolution of gas which was mainly hydrogen with small amounts of methane and higher hydrocarbon gases. The rate of hydrogen production from this tar (and also from bombarded gilsonite) was low, as compared with rates from bombardments of other substances.
12. Bombardment of porphyrin complex resulted in some disintegration. However, it was concluded that presence of porphyrins in petroleum could not be taken as evidence that radioactivity has played no part in generation of petroleum.

Comments and conclusions—Project 43(c).—Uninterrupted work now to be anticipated with the war over, should produce accelerated progress in the radioactivity phases of Project 43. Greater efficiency may be expected in the analytical work on bombardment products. It is expected that alpha-particle bombardments will be carried out under temperatures and pressures parallel with those known to obtain in the earth's crust. The attack, so far, has been chiefly on simple organic compounds. The results have laid the

ground-work for study of the effects of radioactivity on the more complex materials, such as occur in source beds.

The bombardments of methane and other gaseous hydrocarbons have yielded large percentages of hydrogen and unsaturated hydrocarbons. Such compounds are either not present in crude oils or if present, are there in very minor percentages. However, there is always the possibility that if hydrogen and unsaturated hydrocarbons were produced by radioactivity in the earth, they have subsequently entered into combination with other compounds, which in turn have been incorporated into petroleum and natural gas. No mechanism for such combinations has been suggested. The process, therefore, remains improbable, though not impossible.

Bombardments of liquid hydrocarbons gave similar high percentages of unsaturates, with perhaps relatively higher yields of unsaturated liquid hydrocarbons. Here again, we are confronted with the fact that such unsaturated compounds are either absent in rocks or else present in only very minute quantities. Since petroleum in the reservoir rocks must have been exposed to radioactive substances, some of these unsaturates must have been formed. No satisfactory explanation of their absence has yet been advanced.

Bombardments of saturated fatty acids yielded, among other products, liquids which were apparently the corresponding saturated hydrocarbons. These results encourage the hope that further studies will show that radioactivity in the sediments may evolve, from organic materials, some of the saturated hydrocarbons that are found in petroleum. It remains unexplained, however, why after the fatty acids are decarboxylated by radioactivity, the same radiations do not further break up the resulting hydrocarbon molecules, with production of hydrogen and unsaturated hydrocarbons. This is a question requiring further study.

As with the other materials, bombardments of tar oil and gilsonite resulted in evolution of hydrogen and methane, thus indicating changes in the direction of unsaturation, contrary to the direction expected in transformation to typical crude oils. Much more work remains to be done in the bombardment of the natural hydrocarbon complexes and organic materials found in nature. If the results to date do not seem to point to one of the direct methods of petroleum genesis, they are nevertheless pertinent to our problem. From many measurements made during recent years, we know many sedimentary rocks, and particularly those high in organic material, are radioactive. Our knowledge of petroleum genesis will not be complete until we learn more about the effects of such radioactive sedimentary materials on the associated hydrocarbons and other organic material.

COMMENT ON THEORIES OF ORIGIN OF OIL

The various theories on the origin of oil are well outlined in many reports[6] and, with the exception of some observations on the organic theory, are not listed here. The organic theory of the origin of oil as commonly accepted to-day, can briefly be summarized as follows.

All organic materials, in the first instance, were originated by plants, therefore plants are the real originators of oil. Aside from the small percentage of hydrocarbons normally made during life processes, the other remains of plants and animals are composed to a large extent of carbon and hydrogen, the two essential elements of petroleum and natural gas. The organic materials collect in ocean muds, preferably in closed basins where oxygen is deficient and reducing conditions prevail and the non-hydrocarbon organics either are transformed by bacteria into oil soon after burial, or are

[6] F. W. Clarke, "Data of Geochemistry," *U. S. Geol. Survey Bull. 770* (1924), pp. 740–55.
W. E. Pratt, *Oil in the Earth*, Univ. Kansas Press (1943), pp. 11–23.
H. W. Hoots, "Origin, Migration, and Accumulation of Oil in California," *California Div. Mines Bull. 118* (1941), pp. 252–75.
P. D. Trask, "Inferences about the Origin of Oil, as Indicated by the Composition of the Organic Constituents of Sediments," *U. S. Geol. Survey Prof. Paper 186-H* (1937), pp. 147–57.

preserved from decay, and over geological time are converted into oil by radioactive emanations, heat, and pressure, assisted by the ever present catalytic effect of the sediments. Much of the transformation of the organic matter probably occurred contemporaneously with the period of greatest volume reduction during and as a result of initial compaction by the weight of overlying beds.

As compaction proceeds, the hydrocarbons and hydrocarbon-like materials move out of the muds along with other dehydration fluids. The first liquid oil available in the sediments would form an oily phase insoluble in water. This ancestral petroleum could dissolve such organic material as pigments, waxes, and fatty acids, either nearby or during the process of migration. During migration, the filtration and catalytic effect of the sediments would modify the hydrocarbons. These fluids travel in the direction of pressure relief. Apparently, unconformities and sheet sands are main avenues of escape. The oils and gases are trapped when their upward movement through a porous medium is arrested. Additional crops of oil may be generated when compaction processes are revived after the "setting" of the original compaction. This rejuvenation of compaction may be caused by additional weight of overburden, diastrophism, faulting, etc. The evolution of oil through geological time, or increased overburden, is supposedly marked by a decrease in molecular weight (complexity) and increasing hydrogen-to-carbon ratio. Contamination of oil with sulphur or oxygen, or their compounds, arrests or even reverses this process. The natural chemical transformation of oil probably is accomplished by methods somewhat like those now used in our refining manufacturing plants but more slowly and at lower temperatures.

American literature is rich in suggestions of a mixed plant and animal origin for petroleum. The vanadium content of the ash from many young crudes suggests an animal origin. The nitrogen bases of some California crudes denotes a protein origin, perhaps mainly from animals. Brines associated with petroleum in the San Joaquin Valley, California, exceptionally rich in iodine, may indicate a sea-weed origin. The recent recognition of organic acids in oil-field gases and brines indicates an organic origin.

Wherever sediments are laid down enclosing vegetable and animal matter (including water-soluble organic matter) in the presence of salt water under an impervious cap, retention of hydrocarbons and transformation into hydrocarbons are possible. Petroleum is generally present wherever sedimentary rocks are present. Practically no sedimentary basin has been proved to be barren of petroleum. The total amount of disseminated hydrocarbons in ancient sediments is large.

It is estimated that the ultimate crude resources of the world may amount to approximately 600 billion barrels (approximately 23 cubic miles). This estimate is for profitable production at current conditions with no allowance made for improvements in recovery. This quantity of oil may seem large in barrels, but it is not when contrasted with the estimated 20-million-cubic-mile content of the world's sedimentary rocks. Parker Trask reports the average organic content of ancient sediments as 1.5 per cent. If we use this percentage, then our present sedimentary rocks contain 300,000 cubic miles of organic materials. Only 0.01 per cent of this organic material is needed to make the world's ultimate resources of liquid hydrocarbons as we know them to-day.

The quantity of petroleum is also small when compared with carbonaceous materials preserved in sediments. For the United States alone, W. E. Wrather, director of the U.S.G.S., in 1943, estimated the coal and lignite resources at something more than 3 trillion tons. This is equivalent to about 650 cubic miles, which is comparable with the 3 to 4 cubic miles of petroleum which may be approximately the ultimate petroleum resource of the United States.

As stated under the summary of the organic theory, plants are the real originators of hydrocarbons. Plants alone, of all living organisms, have the power to make starches and sugar from the simple materials of carbon dioxide and water. It is estimated that the amount of the sun's energy annually fixed by photosynthesis in the form of starch and sugar, is equivalent to 300 billion tons of coal.[7] We should not feel so discouraged over our lack of more exact knowledge of the origin of oil when science has found no way of duplicating the photosynthetic activity of the green plant.

[7] William J. Robbins, *Sugar Is the Foundation of All Life*. New York Botanical Gardens.

NEED FOR ADDITIONAL RESEARCH ON ORIGIN OF OIL

The three research projects being supported by A.P.I. are far from sufficient to cover the field. Additional projects should be initiated if satisfactory progress is to be made on the origin of oil. We hope that the Research Committee of the A.A.P.G. will sponsor many items which have a bearing on our problem.

When their recommendations and plans for research work have been passed and approved by the Board of Directors, every member of the Association should help to sell the program to those who will finance the work.

One item in particular where we need more information is *the identification of source beds*. If we could finger-print source beds, it would materially help our prospecting, especially in new basins. Source beds might be determined by the character of the remaining organic matter, state of reduction, mineral content, lithology, *et cetera*.

Our knowledge of sedimentary rocks is very deficient. From observed facts on the occurrence of oil worldwide, it might be expected that we should now know its habitat, and the conditions under which source beds were laid down, but we do not. Research work on sediments might help us to determine the areas of most promise for any geological horizon in a given basin.

The chemical nature of the organic materials in sediments is indefinitely understood. Parker Trask[8] found that they consisted mainly of nitrogenous compounds and carbohydrates (largely lignin) with minor quantities of cellulose and ether-soluble constituents. The major constituents of organic matter that are ultimately buried in sediments are complex resistant compounds which have a carbon content of 52–71 per cent, 4–6 per cent nitrogen, 7–10 per cent hydrogen, and 15–35 per cent oxygen. Organic chemistry may or may not be prepared to properly handle our problem. It is extremely difficult to extract the organic material from the sediment without changing its character. We need more exact information on the changes in the organic material of the sediments from the time it was deposited in sea mud of a specific gravity of 1.3 to 1.6 until the sediments reach a specific gravity of 2 or above. The youngest oils recognized come from beds having a general specific gravity of 2. Later, when A.P.I. Project 43 is ready to work on such light marine sediments, the assistance of geologists will be needed in securing the proper large samples. In the meantime, it is hoped that others will work on the chemical nature of the organic materials in sediments.

A study of the organic matter and environmental conditions of marine, brackish, and fresh-water bottom sediments to determine the prevailing physico-chemical conditions favoring the occurrence of oil in marine environments should be continued and expanded.

Plants and animals have the power of assimilating various elements in minute traces; therefore a more critical study of the trace materials in petroleum may furnish valuable information on its origin. Only a small amount of research work has been done on the extraneous materials in crude. Analysis of the ash obtained from several crudes[9] shows the presence of silicon, iron, magnesium, calcium, sodium, potassium, phosphorous, manganese, vanadium, nickel, lithium, copper, aluminum, and lead. Other workers have found, in addition, traces of silver, gold, and arsenic. Sanders[10] made some very important contributions to our problem by his microscopical examination of various crudes. The

[8] P. Trask, "Inferences about the Origin of Oil as Indicated by the Composition of the Organic Constituents in Sediments," *U. S. Geol. Survey Prof. Paper 186-H* (1937).

[9] W. B. Shirey, "Metallic Constituents of Crude Petroleum," *Indus. and Eng. Chemistry*, Vol. 23 (1931), pp. 1151–53.

[10] J. McConnell Sanders, "The Microscopical Examination of Crude Petroleum," *Jour. Inst. Petrol. Technologists*, Vol. 23 (1937), pp. 525–73.

wealth of extraneous material found justifies continued research to see if these vestiges will not furnish some clue as to the origin. Research work along these lines might well be continued and expanded. Only a few electron photomicrographs of crude oils are available. However, they may prove useful in showing the presence, character, and significance of this extraneous material.

As mentioned elsewhere, oil is known to form by the time sediments reach a specific gravity of 2. According to Hedberg's studies,[11] this would represent a depth of burial of approximately 2,500 feet. Geological evidence in certain areas seems to favor the generation of more than one crop of oil. Detailed knowledge of the densities of sediments might help to solve our problem of the origin, migration, and accumulation of oil. This represents a simple research project which can be worked on by all, because most of you have the facilities for making specific-gravity determinations. Eventually, the information will have to be correlated and analyzed by experienced geological research workers.

Since oil is widely accepted as being of organic origin, we wonder what special conditions existed during the periods of the earth's history which produced the greatest quantities of oil. The Miocene, Pliocene, Cretaceous, and Carboniferous are notable producers of oil. Could there have been changes in the ocean currents which brought up water from depth which contained nitrates and phosphates and other minerals which act as food for phyto-plankton? At other times, did the carbon dioxide content of the atmosphere reach such a low point as to cause reduced plant and animal life? Volcanoes supply a great deal of CO_2 into the atmosphere; however, there is no apparent relationship between periods of intense volcanic activity and the generation of oil. At any rate, general studies and research along these lines are indicated.

Several examples are available showing that a given formation may be carbonaceous (coal-bearing) in one part of a basin while grading into a bituminous formation (oil-oil shale) in other parts of the basin. The salinity of the water may be a controlling factor. Research work to determine the inherent differences between the chemical character of carbonaceous and bituminous matter and reasons for the difference may prove quite useful in finding the *origin of oil*. Berl,[12] in experimental work on the carbohydrates, made what he calls a protopetroleum by using an alkaline reactor, but in the absence of alkali essentially coke is obtained. His experiments were not conducted within the "fence" but they may tend to show that an alkaline condition is necessary for the development of bituminous deposits.

Other items of origin research which need attention are: (1) significance of colors and color gradations in sediments with respect to deposition environments and oil source possibilities; (2) correlation of major oil types, based on their physical and chemical characteristics, with geology; (3) study of dry gas distribution to determine the bearing its occurrence may have in outlining the stages leading to oil formation; (4) a study of shale densities to derive more accurately the compaction process and its correlation with oil gravities; and (5) a study of the effect of increased temperatures that prevail in the waters of closed basins.

Although not a research item, it is very important that all new information on the organic content of sediments and sedimentary fluids be made available to the industry. From some of these analyses may come a clue to the origin of oil. In particular, more information is required concerning the presence of hydrogen in formation waters, gases, petroleum, and sediments. The transformation of organic materials is apparently ac-

[11] H. D. Hedberg, "Gravitational Compaction of Clays and Shales," *Amer. Jour. Science*, 5th Ser., Vol. 31, No. 184 (1936), pp. 241–87.

[12] E. Berl, "Role of Carbohydrates in Formation of Oil and Bituminous Coals," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 11 (November, 1940), pp. 1865–90.

companied by the generation of excess hydrogen; however, only very small quantities of hydrogen have been detected in sedimentaries.

SUMMARY AND CONCLUSIONS

Project 43 has now been underway nearly 4 years. Its initiation was the result of many months of hard work by a few of our outstanding petroleum geologists. The three selected projects work on related items varying from the bacterial, to the physico-chemical, to the radioactive emanations effect upon organic matter. The work is kept oriented by a "Geological Fence" which serves to keep the workers from straying beyond the sedimentary environment. Definite progress is being made and all the research workers are enthusiastic and now have a clear conception of the problem. The work thus far has shown that hydrocarbons as such may be due to their production in small amounts by plants and animals, or that they may result from the transformation of organic matter either by physico-chemical, bacterial, or radiation effects. Both bacteria and radioactive emanations produce excess hydrogen in transforming organic material into more hydrocarbon-like products. It is difficult to reconcile this condition with the virtual absence of hydrogen in the sedimentaries.

The war has slowed the work very materially, yet all must appreciate the fact that to discover the origin of oil may require a research project which will run for an additional 15-year period. And, even to accomplish results in this period calls for an expanded program. If the geological fraternity will consistently bear the origin problem in mind, additional bits of information and ideas will surely be uncovered. The object of all this research is to help find oil. If we know how oil is formed, we can find better ways and means of locating the accumulations.

RESEARCH COMMITTEE CALENDAR AND SCHEDULE[1]

(October 1, 1946, to March 24, 1947)

S. W. LOWMAN[2] AND M. A. HANNA[3]
Houston, Texas

CALENDAR

October 1 to November 15	Preliminary formulation of projects should be in hands of the Research Committee chairman on or before November 15 in order to complete the following schedule.
November 16 to Dec. 31	Formulations will be mimeographed and distributed for comment and suggestion, as outlined in the attached memorandum.
January 1 to January 14	Comments and suggestions should be returned to the Research Committee chairman on or before January 1 in order to be available for consideration in possible revision of projects before January 15.
January 15	Meeting of chairmen of subcommittees and project chairmen, Wichita, Kansas. Discussion of projects and preparation of Progress Reports of Research Committee 1947.
February 1	Distribution of Progress Report.

[1] Manuscript received, October 12, 1946.

[2] Chairman, research committee.

[3] Vice-Chairman, research committee.

November 15 to February 15	Consideration of project placement by placement advisory committees.
February 16 to March 22	Preliminary formulation of recommendations.
March 23 to 24	Los Angeles, pre-convention conferences.
Sunday, March 23	Final formulation of projects; discussion of project placement, and final recommendations. Discussion of symposia on oil-producing basins.
Monday afternoon, March 24	Review of projects and symposia. Report to Business Committee.

SCHEDULE

As a result of last year's reconnaissance survey of research needs in petroleum geology, the Research Committee, in a pre-convention meeting at Chicago, March 31, 1946, recommended nine fundamental projects as needing formulation. The Executive Committee has approved this list and chairmen of the projects have been appointed as follows.

SUBCOMMITTEE ON RESERVOIR FLUIDS, RELATED CONSTITUENTS AND CONDITIONS

G. Clark Gester, Chairman, 1945–46, 1946–47

Project 1. Clay Minerals project.—The identification, description, parameters, and behavior of clay minerals in sedimentary rocks as related to all types of well logging, core analyses, reservoir behavior, source beds of petroleum, base exchange, indices of sedimentation environment and variation in permeability, porosity and fluid saturation with burial and compaction. Roland Beers.

Project 2. Hydrocarbons project.—An effort will be made to establish valid indices of the evolution of petroleum as determined by stratigraphic age, depth of burial and original depositional environment. Accepted indices will be applied as criteria of suggested hypotheses of the origin, migration, and accumulation of oil. F. M. Van Tuyl.

Project 3. Formation Waters project.—Application of established and new techniques to a systematic program of analysis of formation waters in selected depositional basins in search of possible gradients or trends in water composition which may lead to new criteria for the discovery of oil. Walter R. Berger.

Project 4. Bacteria project.—Investigation of the occurrence and activity of bacteria in reservoir fluids as an aid to the appraisal of the role of bacteria in the formation and transformation of petroleum hydrocarbons. Project chairman not yet announced.

(Related or parallel experiments are being conducted as a part of A.P.I. Research Project 43A, but the aforementioned project proposal would not duplicate efforts.)

SUBCOMMITTEE ON STRATIGRAPHY AND SEDIMENTATION

G. Marshall Kay, Chairman, 1945–46

SUBCOMMITTEE ON SEDIMENTATION

William C. Krumbein, Chairman, 1946–47

Project 5. Modern Sediments project.—The investigation of sediments of the northern part of the Gulf of Mexico with reference to the physical, chemical, and biological factors in the environment, deposition, and diagenesis. Shepard W. Lowman.

Project 6. Ancient Sediments project.—Comprehensive study of the sediments of a single limited stratigraphic section over a considerable area. W. C. Krumbein.

Project 7. Carbonate Rocks project.—The study of the nature and manner of origin of porosity and permeability in carbonate rocks. W. C. Imbt.

Project 8. Cementation project.—The investigation of the cementation of sedimentary rocks and its bearing on oil occurrence. W. A. Waldschmidt.

SUBCOMMITTEE ON TECTONICS

Philip B. King, Chairman, 1945–46, 1946–47

Project 9. Salt Dome project.—Mapping the flow structure of the interior of salt mines, Texas and Louisiana.

Professor Robert Balk, Mount Holyoke College, South Hadley, Massachusetts, has completed, at the invitation of the Association, a reconnaissance investigation of the salt mines and has prepared a formulation of the project.

Chairman King has subsequently recommended two additional projects, which have not yet been passed on by the Executive Committee. These are project 10, Classification of Fault Systems, to be formulated by him, and Project 11, Laboratory Experiments in Tectonics, project chairman not yet announced.

PRELIMINARY FORMULATION OF ALL PROJECTS COMPLETED BEFORE NOVEMBER 15 WILL BE DISTRIBUTED AS FOLLOWS

First, to geological societies affiliated with the A.A.P.G. and sections of the Association (number of copies equal to about ten per cent of the membership). Purposes.—(1) To obtain discussion and comments of the membership, either individually or in forums, concerning the geological and engineering application of the proposed projects as formulated, their technical features, relationship to currently active research, and possibilities for placement. (2) These projects will probably suggest others, and it is hoped that statements of these will be sent to us, both as additional project suggestions and for the light they would throw on the current projects.

Second, to Winthrop P. Haynes, for transmittal to some of the groups in foreign areas, with requests for comment as to ways in which the project might apply to their areas, or might be revised so as to apply better.

Third, to members of the Research Committee acting in a liaison capacity with other scientific societies: American Institute of Mining and Metallurgical Engineers, Petroleum Division, Parke A. Dickey; Geophysical Union, W. T. Thom, Jr.; National Research Council, P. B. King; Society of Economic Geologists, K. C. Heald; Society of Exploration Geophysicists, J. A. Sharpe. (Liaison with the Geological Society of America, the American Petroleum Institute, and the Federal and State geological surveys are considered under a later section of this memorandum.) Purposes.—(1) To identify possible areas of overlap of the proposed project with currently active research, or conversely to discover areas of needed research, which, though not included in the project, are closely related to it and would enhance its value. (2) To obtain suggestions as to possible placement.

Fourth, to those known to be unusually interested in the technical subjects included in the project. Purposes.—To obtain comment on (1) the technical features of the project, (2) possible areas of overlap with other research, (3) closely related areas, not included in the project, and, (4) suggestions as to possible placement.

There are two principal drawbacks to the proposed wide circulation of preliminary formulations. These are: (1) A possible tendency on the part of project chairmen to delay release of preliminary formulations because of such wide circulation, and (2) the time required for such extensive consultation would tend further to delay action.

We believe, however, that these drawbacks can be overcome by coordination and adherence to schedules, and that they are more than offset by the following potential benefits: (1) keeping the membership of the Association informed of our program and our progress, and recruiting more research thinking, (2) bringing the experience of a large portion of the membership to bear on the projects, (3) developing ideas as to possible placement of projects.

COMMENTS AND SUGGESTIONS REQUESTED BY JANUARY 1

The Research Committee would appreciate receiving comments and suggestions from those to whom copies of the preliminary formulations are sent. While January 1 is the deadline for such suggestions, if they are to receive the attention they deserve before the January 15 meeting in Wichita, it would be impossible to handle much volume at the last minute, and we ask, therefore, that you give these projects your consideration as soon as possible after receiving them.

REFORMULATION OF PROJECTS, JANUARY 15

The volume entitled "Progress Reports of the Research Committee, January 15, 1946" served two useful functions. First, it set a deadline for the completion of the first step of our surveys, and, second, it provided a means of advising the members of the Association concerning the progress of our activities, and thereby served as an important catalyst for the open forum discussions at the Chicago meeting. Both of these considerations operate with equal strength this year.

The mid-year meeting, at Wichita, Kansas, January 16 and 17, will provide an excellent opportunity to discuss our projects, and put the finishing touches on our progress reports. The location is central and mid-January is the best time for preparation of a volume of progress reports designed for distribution before the annual meeting.

It is suggested that project chairmen might find it useful to call meetings of their committees at Wichita on January 14.

We urge that all project chairmen and chairmen of the three main subcommittees plan to be at Wichita on January 15 to discuss the projects and complete our progress report.

CONSIDERATION OF POSSIBLE PLACEMENT OF PROJECTS
November 15 to February 15

The A.A.P.G. has no funds for the support of a major research program, and it is the opinion of a large majority of members consulted, that it is inappropriate for the Association to solicit funds for the support of such a program. Therefore, our nine approved projects do not constitute a "research program" (as misstated in the second objective, Research Notes, October *Bulletin*, 1945), but rather a "group of projects" to which we have contributed our experience and our time, in the expectation that some of them will have sufficient merit to enlist the interest of others.

Project formulations will be sent, on and before November 15 and on January 16, to three groups of men who have agreed to advise us as to the possibility of placing them with various agencies who do or support research in the fields represented by the projects.

These three groups will consider the projects from the viewpoint of

(1) The American Petroleum Institute

(2) The Federal and State geological surveys

(3) The Geological Society of America, research foundations, and universities.

In addition, T. V. Moore will consider our proposed projects in their relationship to A.P.I. Project 43.

PRELIMINARY FORMULATION OF RECOMMENDATIONS
February 16 to March 22

Upon receiving the advice of the placement advisory groups, the chairman and vice-chairman of the Research Committee will formulate a preliminary recommendation and send it to the author of the project and the chairman of the subcommittee to which the project is assigned, for their discussion. The resulting recommendation will be presented at the pre-convention conferences March 23.

PRE-CONVENTION CONFERENCES, LOS ANGELES

The pre-convention conferences of the Research Committee at Chicago on Sunday, March 31, 1946, served the useful purposes of reviewing our year's work and preparing our recommendations to the Executive Committee.

There will be more work to be done at the coming conference in Los Angeles than there was at the last one, and all day Sunday is set aside for these discussions.

It is planned to adopt at the Sunday conferences a final formulation for the projects, to discuss possible areas of common interest with other societies, to review suggestions as to possible placement, and to prepare our recommendations.

OIL-PRODUCING BASINS OF NORTH AMERICA

Following the discussion of individual projects, the subject of symposia on oil-producing basins of North America should be given intensive consideration. Several plans havbeen considered during the year by which a continuing flow of ideas from the many different areas in the country might be obtained. We have also considered ways in which the results of work done on projects being formulated at the present time might be channeled back to oil producing areas most successfully. A series of concurrent symposia on the oil producing basins of North America appears likely to achieve both objectives and at the same time, to produce valuable compilations and syntheses of pertinent data.

OPEN FORUM, MONDAY AFTERNOON

The Research Committee open forum on Monday afternoon could be organized in either of two ways.

(1) As four concurrent conferences on the four groups of subjects included under Sedimentation (4 projects), Tectonics (3 projects), Reservoir Fluids, Related Constituents, and Conditions (4 projects), and the symposia on sedimentary basins.

(2) As a single conference at which would be presented a ten-minute review of each of the eleven fundamental projects, including suggestions as to possible placement, with five minutes discussion, and a one-hour discussion of symposia on oil-producing basins of North America.

The first plan has the virtue of providing more time for the exchange of views by specialists. Plan two, while being condensed, has the virtue of presenting a general picture of all projects at one meeting and thereby emphasizing the synthesis and integration of the group of projects as a whole.

We recommend the second plan because the Sunday conferences are expected to fulfill part of the function of plan one, and also because we believe that many of the members of the Association would prefer the arrangement which would permit their attendance at the discussion of all eleven fundamental projects and the symposia on oil-producing basins as well.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 11 (NOVEMBER, 1946), PP. 1955-1959

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

REVIEW OF PETROLEUM GEOLOGY IN 1945, BY F. M. VAN TUYL, W. S. LEVINGS, AND OTHERS

REVIEW BY ROBERT F. WALTERS[1]
Tulsa, Oklahoma

"Review of Petroleum Geology in 1945," by F. M. Van Tuyl and W. S. Levings, with the cooperation of Ben H. Parker, C. A. Heiland, J. Harlan Johnson, A. W. Buell, and H. V. W. Donohoo, *Quar. Colorado School of Mines*, Vol. 41, No. 3 (Golden, Colorado, July, 1946). 203 pp. (including 58 pp. bibliography). Price, single copy, $2.00; if payment accompanies order, $1.50.

This, the fourth of the annual Reviews of Petroleum Geology, covers developments during 1945 in the basic geologic sciences and in borderline fields related to petroleum geology. As a result of the "splendid cooperation" of petroleum scientists, Van Tuyl, Levings, and other cooperating authors have prepared a text and bibliography more complete than in earlier issues. The preparation of this Review is a project sponsored by the research committee of the American Association of Petroleum Geologists.

The text of the Review is divided into two parts: (1) a narration and evaluation of 1945 developments and publications, and (2) a 58-page bibliography arranged under topic headings corresponding with the text.

The first chapter, "Important Developments of the Year," lists news items of interest to geologists. These include an account of geological honors awarded during the year, necrology, the role of geologists during the war, and significant investigations now in progress.

A number of fundmental topics are reviewed under "Advances in Petroleum Geology and Allied Subjects." These include new maps and publications of general interest, contributions to fundamentals of petroleum geology (properties of petroleum, origin, migration, reservoirs, oil-field waters), and developments in basic geologic sciences. In addition, developments in geophysical and geochemical prospecting and petroleum engineering are briefly discussed.

A notable innovation in the present issue of the Review under "World Exploration and Development" is the addition of a section on foreign fields. Excellently written paragraphs by various authorities tersely summarize the present status of oil exploration the world over. Outstanding among these summaries which make available considerable previously unpublished information is a brief digest of development in the Persian Gulf area by E. DeGolyer.

Data on "Production and Reserves" of the world are briefly summarized.

In a chapter on "Trends in Petroleum Geology," the authors, as a result of their review and assimilation of the mass of publications in the field of petroleum geology, point out that

> Among the trends which have become evident in petroleum geology in recent years, five phases stand out. These are:
> (1) A great awakening to the importance of research.
> (2) A trend towards the exploration of deeper prospective horizons.

[1] Gulf Oil Corporation, Gypsy Division, Geological Laboratory. Review received, October 14, 1946.

(3) The greater emphasis on conservation.
(4) The realization that important reserves of oil and gas exist in submerged areas. . . .
(5) The greater interest in foreign reserves and the attendant increase in foreign exploration.

Each of these five trends is discussed and documented with bibliographic references.

This fourth annual review is excellently printed and, on the whole, well arranged. Its usefulness, particularly to the isolated geologist, would be increased if the 1,500 or so bibliographic items listed but not discussed in the text were also briefly abstracted. It is recognized that this would add greatly to the bulk and to the cost of publication. Some saving in space could be made (at slight inconvenience to the reader) by a numerical system of bibliographic references by which the 332 complete titles of important articles listed in duplicate as footnotes in the text could be eliminated. It is further recognized that no abstract will adequately replace the original geological publication. The fundamental records of geologic writing—the geologic map, the graphic well log, and the geologic cross section—can not be abstracted. They can only be catalogued or reproduced. The usefulness of future issues of the Review would be enhanced, therefore, by (1) a greater use of graphs, maps, and illustrations, and (2) by the inclusion of a list of agencies from which microfilm or other photographic reproductions of original articles can be obtained.

As geological science and its resulting literature become increasingly complex, the publication of an annual digest becomes increasingly imperative. The authors and the research committee of the American Association of Petroleum Geologists are to be congratulated for filling this need in the fourth annual "Review of Petroleum Geology."

RECENT PUBLICATIONS

ALABAMA

**Southeastern Geological Society Fourth Field Trip: Southeastern Alabama, September 27, 28, 29, 1946.* 91 mimeographed pages. Folded road map and correlation chart in pocket. Contains paper by F. Stearns MacNeil, leader of the trip, "The Tertiary Formations of Alabama" (64 pp.); road log (18 pp.); bibliography (9 pp.). Copies for sale by the Southeastern Geological Society, Box 841, Tallahassee, Florida. Price, $3.00. Previous field-trip guidebooks of the Society available: 2d trip (SW. Georgia), $4.50; 3d trip (W. Florida), $3.00; Petroleum Directory of Southeastern States, $1.00.

ALASKA

"Alaska Map E," *U. S. Geol. Survey* (1946). 1 sheet, 36×48 inches. A new general map, compiled from data obtained by aerial photographs and ground surveys, showing principal physical and cultural features. For sale by the Director, Geological Survey, Washington 25, D. C. Price, $0.50.

ALBERTA

"Alberta Oil Review for 1945," by J. L. Irwin. 31 pp. Detailed statistics and information regarding the various fields are given, together with statistics for British Empire Petroleum Production from 1932 to 1945. Canadian Dept. of Economic Affairs, Edmonton, Alberta (1946).

ARGENTINA

*"El Subsuelo de la Llanura Cordobesa en Base a la Perforación S. T. 1, con Especial Referencia al Gondwana" (Subsurface of the Plain of Cordoba as Shown by the Drilling of S. T. 1, with Special Reference to the Gondwana), by Otto Schlagintweit. *Córdoba Dir. Minas, Geol. y Indus. Pub. 10* (Córdoba. Argentina, 1946). 39 pp., 3 figs. In Spanish.

APPALACHIANS

"The Texture of Mississippian, Upper Devonian, and Lower Pennsylvanian Sandstones in the Appalachian Basin," by Gordon Rittenhouse and Elaine Cather, *U. S. Geol. Survey* (1946). 28 pp. Mimeographed. Director, Geological Survey, Washington 25, D. C. Free.

"The Texture of Paleozoic Sandstones and Sandy Limestones in the Appalachian Basin," *ibid.* 13 pp. Free.

CALIFORNIA

"Geology and Paleontology of Palos Verdes Hills, California," by W. P. Woodring, M. N. Bramlette, and W. S. W. Kew. *U. S. Geol. Survey Prof. Paper 207* (August, 1946). 145 pp., 37 pls., 16 figs. Supt. of Documents, Govt. Printing Office, Washington 25, D. C. Price, $1.50.

ECUADOR

*"The Geology of the Guayaquil Estuary, Ecuador," by George Sheppard. *Jour. Inst. Petroleum*, Vol. 32, No. 272 (London, England, August, 1946). 13 figs., incl. 9 photographs. Includes discussion of igneous and metamorphic rocks and their association with petroleum.

GENERAL

"Tertiary Stratigraphy in the Northeastern Part of the Wind River Basin, Wyoming," by Harry A. Tourtelot, assisted by Helen L. Nace. *U. S. Geol. Survey Prelim. Chart 22*, Oil and Gas Investig. Ser. (September, 1946). Single sheet, 40×52 inches. For sale by Director, U. S. Geol. Survey, Washington 25, D. C. Price, $0.40.

*"Notes on Estimating Crude Oil Reserves," by K. Marshall Fagin. *Petrol. Engineer*, Vol. 17, No. 13 (Dallas, Texas, September, 1946), pp. 92–94; 2 tables, 1 fig.

*"Practical Application of Geology to Reservoir Analysis," by Wallace W. Wilson. *Ibid.*, pp. 152–66; 5 figs.

*"New Albany Shale," by Guy Campbell. *Bull. Geol. Soc. America*, Vol. 57, No. 9 (New York, September, 1946), pp. 829–908; 3 pls., 7 figs., 2 tables, 75 geologic sections.

"The Airborne Magnetometer," by J. R. Balsley, Jr. *U. S. Geol. Survey Prelim. Rept. 3*, Geophysical Investig. Ser. (1946). 8 pp., 3 maps. Mimeogr. Free on application to the Director, Geological Survey, Washington 25, D. C.

**Petroleum Production Engineering—Oil Field Development*, by Lester Charles Uren. 764 pp., profusely illustrated. Systematic and well balanced treatment of every phase of petroleum production engineering up to the point at which the wells are ready to produce. 6×9 inches, cloth. Published by McGraw-Hill Book Company, Inc., New York (1946). Price, $7.00.

*"Capital Requirements of Crude Oil Production," by Joseph E. Pogue and Frederick G. Coqueron. *Mining and Metallurgy*, Vol. 27, No. 478 (Amer. Inst. Min. Met. Eng., New York, October, 1946), pp. 501–04; 5 figs, 6 tables. Based on a continuing study of the financial aspects of thirty selected oil companies. Included are data on drilling costs per well and the estimated cost of replacing developed crude-oil reserves.

*"The Primary and Secondary Elements of a Fault," by John Challinor. *Proc. Geologists' Assoc.*, Vol. 67, Pt. 3 (London, England, September, 1946), pp. 153–60; 6 figs.

GULF COAST

"Upper Cretaceous Foraminifera of the Gulf Coastal Region of the United States and Adjacent Areas," by J. A. Cushman. *U. S. Geol. Survey Prof. Paper 206* (August, 1946). 241 pp., 66 pls. Supt. of Documents, Govt. Printing Office, Washington 25, D. C. Price, $1.00.

KANSAS

*"Ground Water Conditions in Elm Creek Valley, Barber County, Kansas, with Special Reference to Contamination of Ground Water by Oil Field Brine," by Charles C. Williams and Charles K. Bayne. *State Geol. Survey Kansas Bull. 64*, Pt. 3 (Lawrence, September, 1946), pp. 81–124; 9 figs., 4 tables.

LOUISIANA

"Geological Map of Louisiana," compiled by W. E. Wallace for the Shreveport Geological Society. Blue-line print, 30×42 inches. Scale 1:500,000. Formations indicated by small letters. Can be colored without difficulty. May be purchased from Shreveport Photo Copy Company, Shreveport, Louisiana. Price, $2.50.

MONTANA

"Devonian Stratigraphy of Central and Northwestern Montana," by Laurence L. Sloss and Wilson M. Laird. *U. S. Geol. Survey Prelim. Chart 25*, Oil and Gas Investig. Ser. (September, 1946). Single sheet, 28×44 inches. For sale by Director, U. S. Geol. Survey, Washington 25, D. C. Price, $0.35.

"Structure Contour Map of the Montana Plains, Showing Present or Restored Configuration of Base of Colorado Shale with Respect to Sea Level," by C. E. Dobbin and C. E. Erdmann. *U. S. Geol. Survey* (1946). Sheet, 32×50 inches. Scale, 1 inch equals 10 miles. Director, Geological Survey, Washington 25, D. C. Price, $0.25.

NEW YORK

*"Future Possibilities for Oil in New York State with Comments on Entire Appalachian Basin," by E. T. Heck. *Producers Monthly*, Vol. 10, No. 11 (Bradford, Pennsylvania, September, 1946), pp. 25–28; 6 figs.

PENNSYLVANIA

*"Continental-Marine Mississippian Relations in Northern Pennsylvania," by Bradford Willard. *Bull. Geol. Soc. America*, Vol. 57, No. 9 (New York, September, 1946), pp. 781–95; 2 figs., 4 photographs.

"Oil and Gas Field Property Line Maps of the Titusville Quadrangle, Pennsylvania," compiled by Parke A. Dickey. *Pennsylvania Topog. and Geol. Survey Spec. Bull. 4* (1946). 9 maps, scale, 1 inch equals 2,000 feet, bound together. For sale by Division of Documents, Department of Property and Supplies, 10th and Market Streets, Harrisburg, Pennsylvania. Price, $1.00.

The Valley of Oil, by Harry Botsford. 278 pp., illus. Chronicling the early growth of the first commercial oil enterprises in Pennsylvania. Published by Hastings House, 67 West 44th Street, New York 18 (1946). Price, $3.00.

*"The Taconic Sequence in Pennsylvania," by George W. Stose. *Amer. Jour. Sci.*, Vol. 244, No. 10 (New Haven, Connecticut, October, 1946), pp. 665–96; 3 figs.

RUSSIA

*"On the Carboniferous Deposits of the Lwow Trough," by D. E. Aisenverg, N. E. Brazhnikova, E. O. Novik, and P. L. Shoulga. *Comptes Rendus (Doklady) Acad. Sci. URSS*, New Ser., Vol. 51, No. 1 (Moscow, 1946), pp. 51–54; 1 map. In English.

*"Stratigraphic Section of the Upper Parts of the Visean and Namurian Stages of the Western Slope of the Central Urals," by O. L. Einor. *Ibid.*, No. 2, pp. 141–44.

*"A Contribution to the History of the Reservoirs of the Transuralian Region," by V. S. Sheshukova. *Ibid.*, No. 3, pp. 225–28.

*"Erosion Cycles in the Western Slope of the South Urals during the Ufa Time," by S. G. Sarkissian. *Ibid.*, No. 4, pp. 307–10.

*"New Data on the Tectonics of the Leningrad Province," by A. N. Federov. *Ibid.*, No. 6, pp. 465–66.

UTAH

"Section of Morgan Formation, Pennsylvanian, at Split Mountain in Dinosaur National Monument, Uintah County, Utah," by F. T. McCann, N. D. Raman, and L. G. Henbest. *U. S. Geol. Survey* (1946). 18 pp., 1 fig. Mimeographed. Director, Geological Survey, Washington 25, D. C. Free.

"Geologic Mapping by Means of Graphic Location," by D. J. Varnes. *U. S. Geol. Survey Cir. 12* (August, 1946). 5 leaves, 2 figs. Mimeographed. Director, Geological Survey, Washington 25, D. C. Free.

GEOLOGICAL OCCURRENCE OF OIL IN UNITED KINGDOM—A CORRECTION

In the article by H. R. Lovely, "Geological Occurrence of Oil in United Kingdom. with Reference to Present Exploratory Operations," published in the September BULLETIN, the following corrections should be made:

		Should Read
P. 1508	"C. JURASSIC PROSPECTS"	"B. JURASSIC PROSPECTS"
	"D. PERMIAN (. . .) PROSPECTS"	"C. PERMIAN (. . .) PROSPECTS"
	"E. LOWER CRETACEOUS (. . .) PROSPECTS"	"D. LOWER CRETACEOUS (. . .) PROSPECTS"
P. 1512	"B. JURASSIC PROSPECTS"	"A. JURASSIC PROSPECTS"
P. 1513	"C. CARBONIFEROUS PROSPECTS"	"B. CARBONIFEROUS PROSPECTS"
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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 11 (NOVEMER, 1946), PP. 1960-1968

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ABSTRACTS OF BILOXI MEETING, OCTOBER 24–25

1. HISTORICAL NOTES ON THE GEOLOGY OF MISSISSIPPI, Urban B. Hughes, consulting geologist, Laurel, Mississippi.

Brief summary of the more important historical events in the geology of Mississippi.

2. STRATIGRAPHY AND PETROLEUM GEOLOGY OF BLACK WARRIOR BASIN, MISSISSIPPI AND ALABAMA, F. F. Mellen, Mellen and Monsour, Jackson, Mississippi.

A great triangular area of approximately 35,000 square miles of normal Paleozoic sediments occupies a large portion of northern Mississippi and northwestern Alabama. The Black Warrior Basin, as its extension is herein proposed, is bounded on the east by the southwesterly plunging Appalachian folds; on the south and southwest by the southeasterly plunging Ouachita mountain system; and on the north by the high Ordovician areas in central and western Tennessee. A soft cover of Mesozoic and Tertiary sediments ranges from a feather edge at the Paleozoic outcrop in the northeastern part of the area to around 6,000 feet in central Mississippi. Several hundred test wells have penetrated Paleozoic sediments ranging in age from Cambro-Ordovician to Pennsylvanian. A combined total thickness of sediments penetrated by these wells is about 12,000 feet. Other than a test well in Webster County, Mississippi, which questionably encountered acidic igneous rock, no igneous or metamorphic rocks have been found in the basin. In the Ouachita boundary area south and southwest of the basin, basaltic intrusions of probable Mesozoic age are common in more or less metamorphosed sediments of Paleozoic age. Commercial gas production from Silurian, Mississippian and Pennsylvanian rocks has been insignificant; but the numerous shows of gas and oil, combined with many sharp unconformities and marked lateral lithologic changes, together with many known faults and anticlinal structures, make the Black Warrior Basin one of the large remaining undeveloped potential oil- and gas-producing provinces of the North American continent.

3. SURFACE OCCURRENCE OF CRETACEOUS BEDS IN THE SOUTHEASTERN STATES, Watson H. Monroe, Geological Survey, U. S. Department of the Interior, Washington, D. C.

The Cretaceous sedimentary rocks of the eastern Gulf region crop out in a crescentic band around the southwestern end of the plunging Appalachian Highlands in a belt 500 miles long and up to 75 miles wide. Their maximum thickness at the outcrop is estimated to be about 2,100 feet.

The oldest beds of the eastern Gulf Coastal Plain, the Vick formation, crop out in a small area in central Alabama. The age of the Vick is uncertain, being post-Paleozoic and pre-Tuscaloosa. It is probably Jurassic or Lower Cretaceous.

Above the Vick formation the Upper Cretaceous formations can be correlated fairly closely with the Texas section, the sequence being divisible into several groups of related formations.

The formations equivalent to the Woodbine of Texas include the Cottondale, Eoline, and possibly the Coker formation, the three lower formations of the Tuscaloosa group. These crop out in an arc extending from Marion County in northwestern Alabama to the Coosa River Valley in east-central Alabama.

The formations equivalent to the Eagle Ford formation are the Gordo formation at the top of the Tuscaloosa group and the McShan formation, formerly considered the lower part of the Eutaw formation. These extend from the Tennessee River Valley on the north into Georgia on the east.

The Austin equivalents include the restricted Eutaw formation and the basal formations of the Selma group, the Mooreville chalk and its sandy equivalents, the lower part of the Coffee sand in northeastern Mississippi and southern Tennessee and the Blufftown formation in eastern Alabama and western Georgia.

Above the beds of Austin age the Cretaceous sequence in the eastern Gulf region may be divided most naturally into two sequences: the lower correlated with Taylor marl and the lower part of the Navarro group and the upper correlated with the upper part of the Navarro.

The lower of these two sequences consists of the Demopolis chalk, its sandy northern partial equivalent of the Coffee sand, and its eastern equivalent, the Cusseta sand, and the Ripley formation, which overlies all three units. This stratigraphic sequence extends from southern Illinois to west-central Georgia.

The upper beds of the Cretaceous include the Prairie Bluff chalk and its two sandy equivalents, the Owl Creek formation on the north and the Providence sand on the east. These formations extend from southern Tennessee as far at least as central Georgia, broken in west-central Alabama by overlap by the overlying Midway beds.

Near the ends of the crescentic belt the sequence of deposition is broken by extensive overlaps. As may be expected, internal, progressive overlap is common in all the formations, but extensive overlap indicating crustal warping is especially notable at the base of each of the larger groups discussed.

4. Subsurface Occurrence of Cretaceous Sediments of Mississippi, C. W. Alexander, Dixie Geological Service, and R. M. Harris, Harris and Payne, Jackson, Mississippi.

The Gulf Cretaceous sediments comprise the most significant group of beds as related to the search for and production of petroleum in Mississippi. As a result, natural emphasis has been placed on their study.

This paper, and the sections which accompany it, represent a composite of available knowledge of the beds and the consensus on the, as yet, uncertain features of the stratigraphy of the Gulf Cretaceous.

5. Cenozoic Deposits of Mississippi and Adjacent Areas, Grover E. Murray, Jr., Magnolia Petroleum Company, Jackson, Mississippi.

20,000 feet or more of Tertiary and Quaternary sediments are present in the central Gulf region of southern United States. They comprise a large, seaward-thickening, wedge-shaped sedimentary complex (Gulf Coast geosyncline) composed predominantly of deltaic deposits. Thin, relatively uniform and widespread, marine strata are present between the thick deltaic deposits and on the seaward edges of the deltaic masses. These thin, generally distinctive, marine strata are adaptable on the surface to detailed structural mapping; they also serve as key strata in core-drilling, in tracing surface units into the subsurface, and in the preparation of subsurface structural maps. Fossils present in the marine units determine their position in the standard geological time scale and assist in determining the relative geographic position at the time of deposition. The thick, ladle-shaped, deltaic deposits are normally unadaptable to structural mapping; however, they are readily used in the construction of areal, facies, and isopachous maps. Landward, both marine and deltaic deposits are progressively of a deeper-water environment, the deltaic deposits are progressively more marine.

The Tertiary is represented by four, perhaps five, epochs of deposition, which are, in ascending order, Paleocene, Eocene, Oligocene, Miocene, and Pliocene (?). Each successively younger series of rocks occupies an outcrop position progressively nearer the present coastline. Similarly, each younger rock series has been downwarped less by the thick, geosynclinal sedimentary load and, therefore, has less southwest regional dip. The Midway (Paleocene), Claiborne (middle Eocene), Jackson (upper Eocene), and Vicksburg (Oligocene) groups each contain important marine units. The Wilcox (lower Eocene), Miocene, and Pliocene (?) are primarily deltaic deposits; they constitute the thickest Cenozoic sedimentary accumulations in the eastern Gulf region.

The Quaternary is represented by two epochs of deposition, the Pleistocene and Recent. These deposits are characteristically fluviatile gravels, sands, silts, and clays; they border or fill alluvial valleys and were deposited during or subsequent to the Pleistocene glaciation.

The outcrop patterns of the major rock divisions of the central Gulf Coastal Plain are illustrated by areal geologic maps and stratigraphic sections. The thickness and structural configuration of each division is shown by isopachous and structural contour maps. Representative electrical logs illustrate the electrical pattern of each rock division.

6. STATUS OF MICROPALEONTOLOGY IN THE EASTERN GULF REGION, Henry V. Howe, Louisiana State University, Baton Rouge, Louisiana.

Since the paper by Finch in 1824, which initiated the study of the Cretaceous and Tertiary stratigraphy of the Eastern Gulf region, about 200 papers dealing with the microfossils of Mississippi, Tennessee, Alabama, Georgia, Florida, and South Carolina have appeared. Of these, at least 160 deal primarily with foraminifera, 21 with ostracodes, 11 with bryozoans, and 4 with otoliths. In these papers nearly 700 species of foraminifera, 150 species of ostracodes, 580 species of bryozoans, and 23 species of otoliths have been described as new from these states. Hundreds of other species whose type localities lie in other states or countries have been reported. The formations whose type localities have been reasonably thoroughly studied for their microfaunal content are indicated. Some suggestions of needed studies are made. The paper is accompanied by an annotated bibliography which lists the species which have been described as new from this region.

7. GENERAL GEOLOGY AND OCCURRENCE OF OIL IN FLORIDA, E. D. Pressler, Humble Oil and Refining Company, Tampa, Florida.

The eastern portion of the Gulf of Mexico Basin is divided into provinces on the basis of stratigraphy and subdivided further on the basis of its major structural features. The general area is considered to be a part of the Gulf of Mexico Sedimentary Basin. The Apalachicola Embayment of south Georgia and west Florida has a maximum sedimentary fill of approximately 15,000 feet of clastic sediments, the South Florida Embayment has a maximum fill of non-clastic sediments approaching 20,000 feet, and the area of the Great Bahama Bank is considered to be underlain by a section in excess of 10,000 feet. Anticlines may be the most prevalent type of structure of both embayments, though faulting is probably present, and conditions are favorable for the formation of stratigraphic traps. Oil production has recently been developed from the Lower Cretaceous on the Florida segment of the South Florida Embayment, and additional drilling development is under way. Gravity and core drill are the most widely used methods of prospecting, and it is indicated that additional experimental work is necessary to develop proper seismograph technique. The Sunniland field, Collier County, Florida, has three producing wells that have produced a total of 80,000 barrels of 20 to 24 degree gravity asphalt-base oil. One rig is working in the field, and eight wildcat operations are active in Florida.

8. NEW GEOLOGIC MAP OF TERTIARY FORMATIONS OF GEORGIA, F. Stearns MacNeil, Geological Survey, U. S. Department of the Interior, Dothan, Alabama.

The new map of the Tertiary formations of Georgia is exhibited, with a brief discussion of the stratigraphy.

9. THE FORMATION OF EVAPORITES UNDER MARINE EVAPORATION CONDITIONS, Paul Weaver, Gulf Oil Corporation, Houston, Texas.

Sediments consisting principally of salt, anhydrite and gypsum, potash, and certain types of limestone and dolomite have a wide areal extent in certain stratigraphic units

and are as of persistent a character as many other sedimentary deposits. Depositions of these beds occurred in large bodies of water in an environment where evaporation exceeded precipitation and where the temperature and other climatic factors were so controlling that they impressed upon the beds special traits which have continued through subsequent geologic time, and a study of these depositions, therefore, enables us to deduce the paleogeography and paleo-climate by applying physical and chemical tests to the sediments.

The primary purpose of this paper, therefore, is to show the combined use of physics, chemistry, and geology in the understanding of a particular environment, and to stimulate the geologist to the utilization of other scientific data to the better understanding of sedimentary processes. The paper begins with a discussion of the warming of a body of water by solar energy, and the change in evaporation with increase in salinity up to the point where water has been saturated as to one or more compounds, and then the order in which precipitation takes place as to different minerals. Actual sediments containing these precipitates are then discussed in order to show the time involved in their formation and the physiography and climate of the basin in which they were formed. The changes which take place in these sediments after burial and particularly the ones immediately following deposition, are discussed.

The paper does not go into any detailed sections in any particular salt series, except what may be necessary to demonstrate some particular points, but from the general principles of this type of sedimentation it is believed that geologists, working in areas where there are sediments of this kind, will understand better the particular areas where they are making correlations by subdividing the sediments of this class.

10. Subsurface Correlations of East Texas, North Louisiana, South Arkansas, and Mississippi, Roy T. Hazzard, Gulf Refinining Company, Shreveport, Louisiana.

A series of cross sections is presented, correlating the Cretaceous beds of East Texas through North Louisiana and South Arkansas, into Mississippi.

11. Mesozoic Igneous Rocks of the Northern Gulf Coastal Plain, C. L. Moody, The Ohio Oil Company, Shreveport, Louisiana.

Study of the outcrop areas of igneous intrusions in the Texas, Arkansas, and Georgia portions of the Gulf Coastal Plain furnishes clues which simplify interpretation of igneous rocks found in deep well samples in the Mississippi Embayment. Many of the known centers of later Mesozoic igneous activity, both outcropping and buried, are apparently the sites of ancient volcanoes which furnished to the depositional basins significant amounts of pyroclastic debris now in part preserved in the early and middle Gulf Cretaceous strata. Dikes transect the oldest known sedimentary rocks in the vicinity of the eruptive centers. The oldest igneous rocks of the Coastal Plain may bear a Triassic date; the youngest were emplaced in late Austin or early Taylor time.

12. Geology of West Tepetate Oil Field, Jefferson Davis Parish, Louisiana, Fred W. Bates and Jay B. Wharton, consulting geologists, Lafayette, Louisiana.

The West Tepetate oil field, located in the Louisiana Gulf Coast area, was discovered by the Barnsdall Oil Company and Vincent and Welch in 1944. The presence of the structure was first suggested in 1930 by torsion balance exploration conducted by Vincent and Welch and was subsequently disclosed by various seismograph surveys during 1941 to 1944. The producing section lies below the *Heterostegina* zone in the Middle Miocene, and consists of nine oil- and gas-bearing sands ranging from 7,600 to 9,500 feet in depth. The structure is a gentle, irregularly elongate dome, believed to have been produced by the deep-seated intrusion of salt, though none has been encountered to date. There is about one hundred feet of effective closure at the producing levels. Only one fault has been

proved, though a major regional fault, downthrown on the south, is indicated by seismograph north of the field, probably being a westward extension of the similarly bounding fault in the Tepetate field. The productive limits thus far established enclose 1,400 acres, offering a reserve of 30–40 million barrels of liquid hydrocarbons.

12. THE DELHI, WEST DELHI AND BIG CREEK FIELDS, A. M. Lloyd and R. B. Totten, Sun Oil Company, Dallas, Texas, and Monroe, Louisiana.

The Delhi, West Delhi, and Big Creek fields are in northeastern Louisiana in parts of Richland, Madison, and Franklin parishes.

Production is from Tuscaloosa in Upper Cretaceous and Paluxy in Lower Cretaceous. Sands within a common reservoir constitute the most prolific producing zone. These sands consist of a basal Tuscaloosa sand and various underlying Lower Cretaceous sands in contact at the unconformity. Other producing sands in the Tuscaloosa are lenses in the marine Tuscaloosa above the basal sand. The Big Creek field produces from several lenticular sand members in the marine Tuscaloosa with the basal sand having been overlapped and not being present.

As of July 1, 1946, 236 wells had been drilled in the Delhi, West Delhi, and Big Creek fields, of which 197 were oil-producing, four gas, and 35 were dry and abandoned. The present productive area approximates 7,000 acres. The fields are in stages of development and the ultimate productive area is as yet unknown. The estimate of total recovery is in excess of 200,000,000 barrels of oil at the present stages of development.

The Delhi field was drilled on a seismic structure but subsequently it was found that the accumulation of the oil was due to a stratigraphic trap with structure playing but a small part. The discovery well primarily was located on the theory of a Tuscaloosa pinchout; the small seismic structure was of secondary importance only.

13. GEOLOGY OF THE GILBERTOWN FIELD, CHOCTAW COUNTY, ALABAMA, A. M. Current, The Carter Oil Company, Jackson, Mississippi.

Production in the Gilbertown field is controlled by faulting. The faults, with their relation to production in both the Selma chalk and the Eutaw formations, are discussed. Possibilities of additional chalk production, as well as Tuscaloosa production, are discussed.

14. THE TINSLEY FIELD, F. R. Shroeder and J. B. Storey, Union Producing Company, Shreveport, Louisiana, and Jackson, Mississippi.

The Tinsley field, located in Yazoo County, Mississippi, was discovered in the latter part of 1939. The structure is a faulted anticline and the structural features are displayed by structure maps, isopach maps and geological cross sections. The stratigraphy, reservoir conditions and other available data are summarized.

15. THE CRANFIELD FIELD, ADAMS AND FRANKLIN COUNTIES, MISSISSIPPI, George Zebal, The California Company, Natchez, Mississippi.

The Cranfield field, 16 miles east of Natchez, Mississippi, was discovered in October, 1943, by the California Company's National Gasoline Company of Louisiana No. 1. Though completed as a Wilcox "5,800-foot zone" oil well, gas-distillate sands were tested in the Tuscaloosa Basal sand horizon. The deep Ella G. Lees well No. 9 was completed in June, 1946, as a dry gas producer in the Paluxy formation.

The Basal Sand zone, by July, 1946, had produced approximately 4,250,000 barrels of oil. Total production from the Wilcox zone had been approximately 570,000 barrels.

Deepest penetration into the Cranfield structure encountered the Comanche Paluxy formation, Trinity group, and Washita-Fredericksburg unit. The Gulf series includes the

Tuscaloosa formation, divisible into three members: the shale and marl facies of the Austin unit; and the Selma group. The Eocene groups, Midway, Wilcox, Claiborne, and Jackson, are represented by 6,650 feet of marine sediments.

The Basal Sand reservoir, containing 65 feet of oil and gas-distillate sand, has 320 feet of effective closure. A cycling project is planned for this reservoir. The mid-Wilcox "5,800-foot sand" has a maximum oil-bearing column of 40 feet and an average sand thickness of 11 feet.

The structure is an oval dome almost unbroken by faulting. Geographical location, among other factors, favors the movement of a deep-seated salt mass as mode of origin.

16. THE HEIDELBERG FIELD, JASPER COUNTY, MISSISSIPPI, Tom McGlothlin, Gulf Refining Company, Laurel, Mississippi.

The structure and stratigraphy of the Heidelberg field are briefly discussed. Some general statements are made regarding the average cost of wells, number of wells, and history of development.

MID-CONTINENT REGIONAL MEETING, WICHITA, KANSAS, JANUARY 16 AND 17, 1947

A regional meeting of the American Association of Petroleum Geologists, sponsored by the Kansas Geological Society, will be held at Wichita, Kansas, with the Broadview Hotel as headquarters.

Morning and afternoon technical sessions will be devoted to the presentation of papers on unusual oil fields and future possibilities of the Mid-Continent region.

The Broadview Hotel can not accommodate the entire attendance anticipated, but all requests for reservations should be addressed directly to the Broadview Hotel, which will handle transfers of reservations to the Allis, Lassen, and other Wichita hotels. Each of these is located within one-half mile radius of the headquarters hotel.

It is imperative that the committee know, as near as possible, how many will attend; accordingly, please return promptly the card that has been mailed you, indicating the possibility of your attendance.

Registrations will begin at noon, Wednesday, January 15.

On the night of January 16, a dance is planned.

Some of the papers scheduled for presentation at this meeting are here listed.

UNUSUAL OIL FIELDS

1. Unusual Oil Fields of the Rocky Mountain Province, by C. E. Dobbin
2. Norman Wells Oil Field, Canada, by J. S. Stewart
3. Deep River Pool, Michigan, by K. K. Landes
4. Adams Pool, Michigan, by Rex P. Grant
5. Pools of Geneseo Trend, Kansas, by Stuart K. Clark
6. Marine Pool, Madison County, by H. A. Lowenstam
7. Hugoton Gas Field, Kansas, by L. C. Morgan *et al.*
8. Rangely Oil Field, by J. M. Kirby *et al.*
9. Antioch Pool, Garvin County, Oklahoma, by Lon B. Turk
10. West Edmond Field, Oklahoma, by Robert M. Swesnik
11. Kraft-Prusa Field, Kansas, by R. F. Walters

FUTURE POSSIBILITIES OF MID-CONTINENT REGION

1. Structural Framework of the Mid-Continent Region, by Ira H. Cram
2. Anadarko Basin and Its Oil Possibilities, by Robert R. Wheeler
3. Oil Possibilities of the Las Animas Arch, by Harry W. Oborne
4. Subdivisions of the Arbuckle Dolomite in Western Kansas, by Joseph R. Clair

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MEMORIAL

KARL HOWARD SCHILLING

(1894–1945)

Karl Howard Schilling died of a heart attack on the night of July 17, 1945, at his home in Houston, Texas. He had apparently been in excellent health.

Karl was born at Carlisle, Kentucky, August 14, 1894. He was the son of Theresa T. Stitt and Hugo Karl Schilling. His father was for many years a professor of German at Harvard University. He left there to become head of the German department at the University of California at Berkeley. He held this position until retirement. Karl's mother was the former Theresa T. Stitt, the daughter of an old Kentucky family.

The early years of Karl's life were spent at Cambridge, Massachusetts. He moved to Berkeley, California, at the age of seven, and all his education was received in the Berkeley schools. He graduated from Berkeley High School in December, 1912. He then worked six months as a roustabout in the Coalinga oil field for the Standard Oil Company of California until time for matriculation at the University of California in August, 1913. He was granted the A.B. degree in May, 1917, and was graduated as a Major of Cadets. While in the university, he studied geology as a major subject.

Directly after graduation, he and Carroll N. Wagner, another graduate, were requested by the geological department of the University to do special oil reconnaissance work in the San Emigdio Valley. Upon completion of this special assignment they published together a paper called "The San Lorenzo Group of the San Emigdio Region, California."

For this they both received the M.A. degree in geology at the University of California early in 1918.

Karl then received his appointment to Officer's Training School at Camp Fremont, California. He was graduated and received his second lieutenant's commission in the summer of 1918. He was sent overseas as an intelligence officer assigned to headquarters of the 8th Infantry of the regular army. The unit arrived in France shortly before the armistice.

Because it had had no combat activity, the whole unit was assigned to billeting and maintaining the embarkation camp at Pontanezen, Brest, France. As his intelligence training was no longer useful and billeting became very monotonous, Karl and another lieutenant received the permission of their commanding officer to establish a camp newspaper. Karl became manager and Lieutenant Neil Allen editor of the *Pontanezen Duckboard*, which they had printed by a local French press. This paper was continued as a great success until the camp was closed.

The unit to which Karl was attached was one of the last to remain overseas. It returned to New York in August, 1919, at which point Karl received his discharge.

Karl Schilling spent his entire work life in the service of the Shell Group of oil companies. He did work in many places.

His first assignment as a geologist was in Peru in late 1919 and early 1920 for the Shell of California. This was a reconnaissance examination of a large territory. In this work he was an assistant to W. van Holst Pellekaan and J. T. Singewald, Jr., of the Johns Hopkins University.

Upon his return from Peru he was assigned to duty with the Matador Petroleum Company with headquarters at Cheyenne, Wyoming. He worked in Utah under E. F. Davis with headquarters at Salt Lake City from June, 1920, to March, 1921.

Schilling went to Venezuela as a field geologist on a special assignment with F. E. Vaughan in May, 1921. He worked over large regions in reconnaissance. This work was finished in May, 1922. He then returned to the United States and was assigned to the Roxana Petroleum Corporation with headquarters at Tulsa, Oklahoma. Here he began his many years' work as an interpreter of subsurface geologic structure. After four years in the interpretation of Oklahoma geology he was sent to Dallas where he spent the period of 1926 to 1930 in study of Texas geologic structure.

Mr. Schilling went to Michigan in 1930 and was a pioneer in the interpretation of subsurface geology through the early years of the Michigan oil industry. His work in Michigan was finished in 1938, and he was transferred to Shreveport, Louisiana. He worked in Shreveport until September, 1941.

He began his duties in the main office at Houston as an expert assigned to the study of special and unusual geologic problems in September, 1941. He remained in this work until the time of his death. It was in the non-routine phase of his last assignment that his powers of geologic thinking and visualization came into full use. It was at this period of his career he probably was of greatest service to his employer. He was cut down by the grim reaper at the height of his usefulness.

Karl Schilling is survived by his wife, Coe McCabe Schilling, and by two daughters, Coe Elizabeth and Beth, and one sister, Mrs. Newton B. Drury of Glencoe, Illinois.

Karl Schilling was an affable, kindly, considerate, sincere man of the highest moral sensibility. He was a fine husband and father and a steadfast friend. He was the possessor of a fine scientific mind which had been excellently trained. He was a stratigrapher and structural geologist of great attainments. Equally important, he was able to make lucid explanations of his thoughts.

He was a loyal and valuable employee who possessed the rare gift of maintaining excellent personal relations with all fellow employees without respect to rank. He was known widely in the petroleum industry, particularly in exploration circles. He is sadly missed.

Mr. Schilling was a member of A.A.P.G., A.I.M.E., and Theta Tau engineering honor society, and Delta Upsilon social fraternity.

ERNEST G. ROBINSON

HOUSTON, TEXAS
October 1, 1946

JOHN MURO GOLDEN

(1900–1945)

News of the death of Major John Muro Golden in an automobile accident in the vicinity of Marburg, Germany, on September 8, 1945, came as a shock to his many friends in geological and geophysical work.

John was born in New York City on June 17, 1900. He entered the Colorado School of Mines in 1921. After one year of college work, he went into the field and obtained a varied practical experience, at various times working on concrete chimney construction for the Weber Chimney Company of Chicago and also working for the D. & S. L. Railroad in Denver. In 1929 he re-entered the Colorado School of Mines, majoring in geology. He graduated in 1932 with the degree of Geological Engineer. While in school he served one summer as an instructor in surveying and as a recorder for the United States Geological Survey. While in school he was an excellent student, being a member of the honorary fraternities, Tau Beta Pi and Sigma Gamma Epsilon. While at the Colorado School of Mines he was active in R.O.T.C. work and took a commission as Second Lieutenant in the reserve on graduation.

He was married on April 3, 1923, to Frances Hemberger of Golden, Colorado, who was with him on all of his work until her untimely death in Wichita Falls, Texas, on February 17, 1938.

Following graduation from the Colorado School of Mines, John entered the employ of the Independent Exploration Company and was successively shooter, observer, computer, and party chief and enjoyed a high reputation for personal integrity and technical ability. Following his work in the seismograph work, in 1941 he entered the employ of the Elflex

JOHN MURO GOLDEN

Company of Houston, Texas, with which company he was a party chief on electrical-prospecting units.

Having kept up his interest in the army work and being a member of the Reserve Officers Association, John was anxious to do his part, and in April, 1942, he entered the army as a Lieutenant and rose by promotion to the rank of Major. He served in the European theater.

After the death of his first wife, John married Miss Faula Mae Hudman of Sulphur Springs, Texas, in Bowie, Texas, on August 22, 1938. His wife now lives in Harrah, Oklahoma.

John M. Golden was a member of the American Association of Petroleum Geologists, the Society of Exploration Geophysicists, and the Houston Geological Society.

By a tragic coincidence, John's brother Larry was killed in an automobile accident in Detroit on Christmas Eve, 1945, so that John's parents lost both of their sons by automobile accidents in the same year.

John is survived by his parents, Mr. and Mrs. John A. Golden, 142 Hemenway Street, Boston, Massachusetts; by his wife, Mrs. Faula Mae Golden, Harrah, Oklahoma; by his two sisters: Miss Elizabeth Golden, 142 Hemenway Street, Boston, Massachusetts; and Mrs. Rodney Ely, Balboa Heights, Canal Zone.

JOHN H. WILSON

Fort Worth, Texas
October 4, 1946

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

Ross H. LEY was released from military service on June 21, and is now with the Sun Oil Company, Dallas, Texas.

JOHN R. BERG has resigned from the Shell Oil Corporation, Wichita, Kansas, to join the geological department of the University of Wichita as assistant professor.

W. P. JENNY, consulting geologist and geophysicist, is back in Houston after spending several months in Europe.

PARKER D. TRASK has resigned from the University of Wisconsin and has returned to the United States Geological Survey at Washington, D. C. During the past summer, Trask and CARL O. DUNBAR of Yale University and W. W. RUBEY of the United States Geological Survey were the geological members of the group of 21 American scientists and the delegates of the 11 United Nations who were on the U. S. S. Panament, observing the two atomic bomb explosions at Operations Crossroads in Bikini Atoll.

CARL H. BEAL, 57, widely known geologist, died September 7, 1946, in Los Angeles, after a long illness. Beal was a graduate of Stanford University where he later taught in the geological department during the years of 1914 and 1915. Shortly before his death he had completed a lengthy work on "Geology of Baja California." Survivors included his son Carlton, consulting geologist, also of Los Angeles.

FRED M. BULLARD, professor of geology at the University of Texas, taught courses in geology at the 1946 summer school of the National University of Mexico in Mexico City for the fourth consecutive summer. Following the summer session, he made a survey of the active volcanoes of Central America, especially in Guatemala, El Salvador, and Nicaragua, under the sponsorship of the University (of Texas) Research Institute.

GORDON I. ATWATER has resigned as chief geologist and manager of the land department for William Helis to open offices in New Orleans as a consulting geologist.

A. LYNDON MORROW, formerly district geologist with the Magnolia Petroleum Corporation at Lake Charles, Louisiana, is now connected with Vincent and Welch, independent operators at Eunice, Louisiana.

On September 20–22 the New Mexico School of Mines and the New Mexico Bureau of Mines and Mineral Resources, Socorro, sponsored a field trip to the San Juan basin. More than 120 geologists attended, from Texas, Oklahoma, Colorado, Utah, Wyoming, Montana, Ohio, and New Mexico. The group spent the first day along U. S. Highway 66 between Albuquerque and Gallup, with side trips to examine the geologic section from pre-Cambrian to Upper Cretaceous. Features of the second day's trip were visits to the helium-treating plant of the U. S. Bureau of Mines at Shiprock, and the Barker Creek dome, which produces gas from the Dakota sandstone and from the Pennsylvanian Paradox formation. On the final day the group visited the Aztec Ruins National Monument and then proceeded across the basin to the Sierra Nacimiento, where strata of Permian, Triassic, Jurassic, and Cretaceous ages were seen. The trip disbanded 17 miles north of Albuquerque. Leaders were Professors GEORGES VORBE and RALPH WILPOLT, department of geology, School of Mines, and ROBERT L. BATES, oil and gas division, State Bureau of Mines and Mineral Resources. In planning the trip they had the active collaboration of JOHN A. FROST, conservation branch, U. S. Geological Survey.

W. L. RUSSELL has resigned from the Stanolind Oil and Gas Company to accept the position of associate professor on the geological faculty of Texas Agricultural and Mechanical College, College Station, Texas. Russell has been with the Stanolind Company for the past 3½ years.

President EARL B. NOBLE has visited local groups and conferred with Association members throughout the Mid-Continent region during the past summer and this fall. A recent itinerary included Midland, San Antonio, Corpus Christi, Austin, and Houston, Texas.

LESLIE BOWLING resigned from the Union Oil Company of California, at Houston, Texas, to accept the position of chief geologist and manager of the land department for William Helis in New Orleans, effective October 15, 1946.

JOHN M. WARE, consulting geologist of Tulsa and formerly assistant manager of the land and exploration department, Deep Rock Oil Corporation, has joined Barnsdall Oil Company as district manager, exploration department for Oklahoma, with offices to be opened in Oklahoma City.

THOMAS A. HENDRICKS, United States Geological Survey, spoke on "The Mineral Resource Situation of the Former Japanese Empire," before the Tulsa Geological Society, October 4. Hendricks recently returned from a tour of duty as chief of the Mining and Geology Division of Natural Resources Section, General Headquarters, Tokio.

WILLIAM C. KRUMBEIN, department of geology, Northwestern University, Evanston, Illinois, has been appointed by president Noble to be A.A.P.G. representative on the American Geophysical Union subcommittee on permeability.

CHARLES CLARK of Shreveport, Louisiana, is now a trainee with the Carter Oil Company, of Tulsa, Oklahoma. He was in the Army Air Corps 3 years, of which time he spent 21 months as a base weather officer in India and Burma. Charles is the eldest son of CHESTER C. CLARK of the Union Producing Company, Shreveport.

WESLEY G. GISH, formerly vice-president of the Transwestern Oil Company, San Antonio, Texas, is now vice-president of the Deep Rock Oil Corporation, Tulsa, Oklahoma.

PHIL F. MARTYN has resigned his position of chief geologist for the J. S. Abercrombie Company, Houston, Texas, to engage in consulting work. His address is Gulf Building, Houston.

EUGENE W. VANDERPOOL has resigned as geologist for the Stanolind Oil and Gas Company and has opened a residue research laboratory in Midland, Texas.

W. C. IMBT, district geologist for the Stanolind Oil and Gas Company at Midland, Texas, spoke on "Limestone Porosities" at the meeting of the Tulsa Geological Society, October 7.

JOHN H. FETH, who has been a teaching fellow in geology for the past 2 years at the University of Arizona while completing credits toward the Ph.D. degree, is now employed full time at the University.

PARRY REICHE has left the University of New Mexico to join the Bureau of Reclamation at Sacramento, California.

P. E. NARVARTE, engaged for the past 12 years by the Petty Geophysical Engineering

Company in the interpretation of seismic data, has resigned his present position of district supervisor to do geophysical consulting work. His temporary address is 1422 West Hollywood Avenue, San Antonio, Texas.

KENNETH C. ANDERSON is now working in Midland, Texas, for the Standard Oil Company of Texas.

Discharged from the service on July 21, JAMES A. WILSEY, JR., is in the graduate school, Princeton University, Princeton, New Jersey.

Recently discharged from the Navy, ROBERT P. EVANS is now employed in the geological department of the Lion Oil Company, El Dorado, Arkansas.

GLEN C. WOOLEY has resigned from the Transwestern Oil Company to accept a position with the Transwestern Royalty Company, San Antonio, Texas.

RICHARD W. CAMP has been elected a vice-president of the Consolidated Gas Utilities Corporation, Oklahoma City, Oklahoma.

G. H. CROWL has resigned from the Carter Oil Company to accept appointment as assistant professor of geology at Pennsylvania State College, State College, Pennsylvania.

Formerly stationed with the Caribbean Petroleum Company in Caracas, Venezuela, JOHN B. WOOLLEY may now be addressed in care of the Shell Oil Company, Los Angeles, California.

WILLIAM L. KREIDLER is now employed by the International Petroleum Company, Apartado 1081, Lima, Peru. He was formerly on the staff of the Tide Water Associated Oil Company, Shreveport, Louisiana.

Discharged from the Navy, August 15, WALTER W. DOERINGSFELD, JR., is now a graduate student in geology at the University of Michigan, Ann Arbor, Michigan.

Formerly stationed in Modesto, California, with the Western Gulf Oil Company, J. CONRAD HEGGBLOM may now be addressed: Gradco, Box 375, LaJunta, Colorado.

WARING BRADLEY is now employed in the electrical well-surveying division of the Halliburton Oil Well Cementing Company, Midland, Texas.

T. G. ROBERTS, formerly with the Shell Oil Company in Tulsa, Oklahoma, may now be addressed: Department of Geology, University of Kansas, Lawrence, Kansas.

GEORGE G. HUFFMAN has resigned as geologist for The Texas Company to accept a position on the staff of the School of Geology at the University of Oklahoma, Norman.

J. M. BROWNING has been transferred from the International Ecuadorean Petroleum Company to the Tropical Oil Company, Bogota, Colombia.

WILLIAM R. HIGGS has left the Carter Oil Company to be an instructor in geography while working on his M.A. degree in geology at the University of Alabama.

FRED F. KOTYZA has resigned from the Fullerton Oil Company to join Kerr-McGee Oil Ltd. as geologist in the Midland, Texas, office.

F. G. Fox has left the Imperial Oil Ltd., Calgary, Alberta, to take post-graduate studies at the University of Oklahoma, Norman, Oklahoma.

At a business meeting held September 30, 1946, D. R. GUINN tendered his resignation as president of the East Texas Geological Society. The following officers were elected to serve until April 15, 1947: president, T. H. SHELBY, Humble Oil and Refining Company, Box 2025; vice-president, GEORGE N. ELY, Continental Oil Company, 907 Peoples Bank Building; and secretary-treasurer, B. F. MURPHY, Amerada Petroleum Corporation, Box 2026; all of Tyler, Texas.

The department of geology and mineralogy of the University of Minnesota announces appointment of FREDERICK M. SWAIN as assistant professor to teach petroleum geology and micropaleontology. Professor Swain comes to Minnesota from the Pennsylvania State College and earlier associations with Phillips Petroleum Company, the United States Geological Survey and the Pennsylvania Railroad System.

HEINRICH RIES of Ithaca, New York, former head of the geology department of Cornell University and internationally known sand and clay authority, who has been technical adviser to the American Foundrymen's Association sand project since 1929, is chairman of the new Sand Division of that Association.

Acting on a recommendation by A. I. LEVORSEN, President NOBLE announces the appointment of a special A.A.P.G. education committee consisting of two geologists from educational groups and five geologists from industry. The committee is composed of the following: JAMES GILLULY, University of California, chairman; HENRY V. HOWE, Louisiana State University; MORGAN J. DAVIS, Humble Oil and Refining Company; STUART K. CLARK, Continental Oil Company; ROY R. MORSE, Shell Oil Company, Inc.; RONALD K. DEFORD, Argo Oil Corporation; THERON WASSON, Pure Oil Company. This committee will attempt to develop a cross section of Association opinion on matters pertaining to geological education, supplementing the work previously done by LAHEE's committee on this same subject, and will act as a clearing house for the Association on all matters pertaining to geological curricula. The chairman of this committee is authorized to represent the A.A.P.G. on matters pertaining to geological education.

DISTINGUISHED LECTURE TOURS

PAUL H. PRICE, State geologist of West Virginia, made the first tour of the 1946–47 season in October, discussing "Evolution of Geologic Thought in Prospecting for Oil and Natural Gas." Price's experience in the surroundings where I. C. White advanced the anticlinal theory of oil accumulation gave him intimate knowledge of the early geological ideas which have been in the process of evolution since geology and oil were first combined in one thought. In the course of his tour, he visited the following societies.

October
7—Illinois Geological Society
8—Indiana-Kentucky Geological Society
10—San Joaquin Geological Society
11—Pacific Section A.A.P.G.
15—Alberta Geological Society
18—Wyoming Geological Society
21—Tulsa Geological Society
22—Kansas Geological Society
23—Oklahoma City Geological Society
24—Shawnee Geological Society
25—Ardmore Geological Society
28—West Texas Geological Society
29—South Texas Geological Society
30—Houston Geological Society
31—Fort Worth Geological Society

November 1—Dallas Geological Society
2—East Texas Geological Society
4—Shreveport Geological Society
5—Mississippi Geological Society

WILLIAM O. HOTCHKISS, president of the Society of Economic Geologists, president-emeritus of Rensselaer Polytechnic Institute, and an authority on mineral resources of the world, addressed the following geological groups in November on the subject "The Non-Fuel Minerals and National Defense." He stressed the critical shortages in the United States and suggested remedies for this situation.

November 4—Pittsburgh Geological Society at Pittsburgh, Pennsylvania
6—Ohio State University at Columbus
8—University of Illinois at Urbana
11—Tulsa Geological Society at Tulsa, Oklahoma
12—New Orleans Geological Society at New Orleans, Louisiana
13—Southeastern Geological Society at Tallahassee, Florida
15—Houston Geological Society at Houston, Texas
18—South Texas Geological Society at San Antonio
20—North Texas Geological Society at Wichita Falls
21—Panhandle Geological Society at Amarillo, Texas
22—Rocky Mountain Association of Petroleum Geologists at Denver, Colorado
25—Wyoming Geological Association at Casper

WALLACE E. PRATT, a former president of the Association, and recently a vice-president of the Standard Oil Company (New Jersey), appeared before the following societies, with "Petroleum on the Continental Shelves" as the subject of his lecture.

November 4—Texas Technological College, Lubbock
8—Pacific Section, A.A.P.G., Los Angeles California
11—Wyoming Geological Association, Casper
12—Rocky Mountain Association of Petroleum Geologists, Denver, Colorado
15—Illinois Geological Society, Champaign-Urbana
December 2—Tulsa Geological Society, Tulsa, Oklahoma
4—Kansas Geological Society, Wichita
6—Oklahoma City Geological Society, Oklahoma City
9—Dallas Geological Society, Dallas, Texas
10—Fort Worth Geological Society, Fort Worth, Texas
12—West Texas Geological Society, Midland

LLOYD W. MADDEN is now working for the Shell Oil Company, Inc., 2000 Alamo National Bank Building, San Antonio, Texas.

CHESTER F. BARNES has left the Cosden Petroleum Corporation to enter private practice as a consultant in geology and geophysics. His new office address is 204 Petroleum Building, Big Spring, Texas. Prior to his recent connection with the Cosden Petroleum Corporation, Barnes was employed by the Humble Oil and Refining Company, Houston, Texas.

CLIFFORD L. WILLIS, formerly with the Carter Oil Company, Wichita, Kansas, may now be addressed in care of the department of geology of the University of Washington at Seattle, Washington.

OSCAR HATCHER has resigned as chief geologist with Helmerich and Payne, Inc., and will operate independently, with headquarters in Tulsa, Oklahoma.

HENRY CARTER REA has resigned as administrative and Rocky Mountain division geologist for the Bay Petroleum Corporation and has opened consulting offices in Casper, Wyoming. Rea will offer to the industry an exclusive service in the geological interpretation of aerial photographs.

PAUL FARMER is a geologist with the Gulf Refining Company, Box 482, Mattoon, Illinois. PAUL H. FARMER, not of the Gulf Refining Company, as stated in the October BULLETIN, is reported as having joined the Brinkerhoff Drilling Company, Evansville, Indiana.

LOIS J. SCHULZ has resigned from the Stanolind Oil and Gas Company and is now with The California Company at Tallahassee, Florida.

VINTON A. BRAY has been transferred from the Socony-Vacuum Oil Company at Caracas, Venezuela, to Compañia de Investigacion y Exploitaciones Petroliferas, S. A., Madrid, Spain.

EDWARD L. MOORE, of Cornwall, England, is with the Socony-Vacuum Oil Company at Avenida Wilson 810, Lima, Peru.

EDWARD E. GILBERT, who has been with the Sun Oil Company at Calgary, Alberta, has returned to finish his work for a B.A. degree at the University of Wisconsin at Madison.

J. E. BRANTLY, formerly president of the Association of Oilwell Drilling Contractors, was a featured speaker at the convention of that Association in San Antonio, Texas, October 1 and 2. He is president of the Drilling and Exploration Company, Inc., Dallas, Texas, and Los Angeles, California.

J. C. MARTIN, JR., has resigned his position as geologist with the Crown Central Petroleum Corporation to join the geological staff of the Texas Gulf Producing Company in Houston, Texas.

JACK HIRSCH has resigned as geologist with The Texas Company located at New Orleans to open a consulting office in Mattoon, Illinois, covering principally the tri-state area of the Illinois basin. His office address is Room 401, Lumpkin Building, and his mailing address, Box 442, Mattoon, Illinois.

RODMAN K. CROSS has resigned as district geologist of the Los Angeles basin, California, for the Richfield Oil Corporation, and has joined the exploration department of The Hancock Oil Company of California, 2828 Junipero Avenue, Long Beach, California.

J. E. LEE, JR., has resigned as chief geophysicist with Kerr-McGee Oil Industries, Inc., to become president of the American Exploration Company, 222 Polk Street, Lafayette, Louisiana.

RUSSELL H. DICKEN, formerly with the Plymouth Oil Company, Miami, Florida, is now a consulting geologist with headquarters at 3772 Rice Boulevard, Houston 5, Texas.

WILLIAM L. CHASE, formerly of Pasadena, California, is general manager of the Great Eastern Mining Company, Box 436, Silverton, Colorado.

K. E. ADAMS is now district geologist in Wichita, Kansas, for The Texas Company, Box 1801. He was formerly resident geologist for the same company at Mt. Pleasant, Michigan

JANE T. CARLTON has resigned from the U. S. Geological Survey and may be addressed at 1235 Como Boulevard, St. Paul, Minnesota.

I. L. BURR has moved from New Zealand to Africa, and may be addressed: c/o Shell Exploration Party, Shell Company of West Africa, Lagos, Nigeria.

O. H. KRISTOFFERSON has resigned as district geologist in Michigan for the Skelly Oil Company in order to engage in consulting work, with headquarters in Mt. Pleasant, Michigan.

WILLIAM E. WRATHER, director of the United States Geological Survey, is a member of the United States delegation to the Second Pan-American Congress of Mining, Engineering, and Geology, Rio de Janeiro, Brazil.

HUGH TANNER, who has been working in the Permian basin of West Texas and southeastern New Mexico during the past 10 years, has resigned from the Ohio Oil Company. His address is 710 West Storey, Midland, Texas.

FRED K. FOSTER has left The Chicago Corporation at Shreveport, Louisiana, where he has been for 2 years. He may be addressed at 711 Alamo National Building, San Antonio, Texas.

R. MAURICE TRIPP has resigned from his position as assistant to the president of Geotechnical Corporation, and announces the opening of a consulting engineering office in Lincoln, Massachusetts.

HERBERT V. LEE is entering foreign service for The Texas Petroleum Company, and may be addressed at 159 Apartado Postal, Barranquilla, Colombia. His former home was in Corpus Christi, Texas.

D. H. ELLIOTT, recently of Berkeley, California, and formerly with the International Petroleum Company, Guayaquil, Ecuador, is now in Bogotá, Colombia, with the Tropical Oil Company.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Carlos O. Anderson, Jr., Weeks, La.
H. H. Power, Kenneth A. Ellison, Harold D. Jenkins

James Henry DeLong, Jr., Evansville, Ind.
D. E. Lounsbery, Homer H. Charles, Oscar M. Hudson

Robert Wright Harrison, Houston, Tex.
R. B. Mitchell, E. O. Bennett, Donald I. Gahagan

John Melvin Law, Houston, Tex.
F. W. Rolshausen, R. D. Woods, E. P. Tatum

Sami N. Nasr, Haifa, Palestine
N. E. Baker, F. R. S. Henson, F. E. Wellings

Lawrence Eugene Porter, Los Angeles, Calif.
H. W. Hoots, Robert B. Moran, Glenn H. Bowes

Robert L. Rist, Bakersfield, Calif.
R. G. Reese, H. W. Weddle, R. E. Darke

Homer James Smith, Bogotá, Colombia, S. A.
A. D. Graves, Philip Andrews, J. A. Tong

Edward Allen Vogler, Houston, Tex.
Gordon H. White, Floyd A. Nelson, R. E. McAdams
Joseph Walla, Jr., Caripito, Venezuela, S.A.
James S. Cullison, E. Dumont Ackerman, L. G. Huntley

FOR ASSOCIATE MEMBERSHIP

Veronica Jennie Beckelhymer, Houston, Tex.
L. C. Snider, John M. Brokaw, Jr., Olin G. Bell
Robert William Chesney, Oklahoma City, Okla.
W. L. Moreman, John E. Van Dall, F. E. Wimbish
Kenneth E. Hill, New York, N. Y.
Walker S. Clute, Harold J. Clark, John C. Young
Otto George Holekamp, Lake Charles, La.
C. L. Herold, S. R. Say, J. B. Dorr
Joseph Richard Lanier, Laurel, Miss.
Roy T. Hazzard, Tom McGlothlin, Urban B. Hughes
Melvin N. Levet, Monterey Park, Calif.
L. S. Chambers, R. W. Clark, Vincent W. Vandiver
Duncan Junior McGregor, Lawrence, Kan.
M. L. Thompson, John C. Frye, L. R. Laudon
Edward Bruce Parmelee, Shreveport, La.
J. Brian Eby, Frederick A. Burt, F. E. Turner
William Bird Rodan, Abilene, Tex.
James R. Day, G. J. Smith, J. M. Vetter
John Robert Sanders, Lafayette, La.
J. A. Culbertson, Max Bornhauser, Malcolm D. Bennett, Jr.
Timothy Germer Schmidt, Austin, Tex.
Fred M. Bullard, L. C. Snider, Hal P. Bybee
Carney Ray Soderberg, Lander, Wyo.
B. B. Bradish, George R. Downs, D. L. Blackstone, Jr.
Richard Ross Spurrier, Santa Fe, N. Mex.
W. E. Scott, Glen Staley, Robert L. Bates
John Norman Willson, Edmonton, Alta., Canada
John A. Allan, P. S. Warren, H. H. Beach

FOR TRANSFER TO ACTIVE MEMBERSHIP

Oscar Ebsen Gram, Wichita Falls, Tex.
Paul E. M. Purcell, Hilton L. Rickard, Ralph H. McKinlay
William Taylor Hudson, Rangely, Colo.
J. W. Hoover, K. H. Crandall, H. T. Richardson
Gregg Ferdinand McReynolds, Houston, Tex.
J. E. LaRue, D. P. Carleton, Stanley R. Allen
John Peter Potsch, Cicero, Ill.
L. E. Workman, A. H. Bell, L. A. Mylius
William Adams Riggs, Wilmington, N. C.
Garland Peyton, Victor Cotner, F. Stearns MacNeil
Joseph McHutchon Sears, Oklahoma City, Okla.
Charles E. Decker, F. A. Melton, C. G. Lalicker
Lyle Wyman Smith, Ventura, Calif.
Alex Clark, Paul S. Pustmueller, William H. Thomas
James Robert Tichy, Las Animas, Colo.
Sherwood Buckstaff, John E. Galley, J. B. Leiser

PROFESSIONAL DIRECTORY

ALABAMA

HARRY R. HOSTETTER
Core Drilling Contractor
Specialist in Reverse Circulation Coring
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707 South Hill Street
Los Angeles, California
Vandike 7087

JEROME J. O'BRIEN
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Petroleum Building
714 West Olympic Boulevard
McLarthy & O'Brien Los Angeles 15, Calif.

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601 West Fifth Street
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Consultant in Oil, Gas, Mining
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PAUL P. GOUDKOFF
Geologist
Geologic Correlation by Foraminifera and Mineral Grains
799 Subway Terminal Building
LOS ANGELES, CALIFORNIA

A. I. LEVORSEN
Petroleum Geologist
Stanford University California

ERNEST K. PARKS
Consultant in
Petroleum and Natural Gas Development
and
Engineering Management
614 S. Hope St.
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Core Drilling Contractor
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Los Angeles 6, Calif.

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Surface, subsurface, sedimentation, stratigraphy, paleogeography, wells, reports
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Phone 484-W

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General Petroleum Geology
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University of Cincinnati
Cincinnati, Ohio

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ELFRED BECK
Geologist
308 Tulsa Loan Bldg. Box 55
TULSA, OKLA. DALLAS, TEX.

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Seismograph Service Corporation
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136 East Twentieth Ave.

Secretary-Treasurer - - - - - - A. W. Cullen
1024 Continental Oil Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - - Jack Hirsch
Box 442, Mattoon, Illinois

Vice-President - - - - - - - - E. E. Rehn
Sohio Petroleum Company
Box 537, Mt. Vernon

Secretary-Treasurer - - - - John B. Patton
Magnolia Petroleum Company
Box 535, Mt. Vernon

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - Harold O. Smedley
Skelly Oil Company

Vice-President - - - - - - - Paul A. Harper
Cities Service Oil Company

Secretary-Treasurer - - - Francis E. Mettner
Transwestern Oil Company
605 Union National Bank Building

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - - T. H. Philpott
Carter Oil Company

Vice-President - - - - - - - Brame Womack
Sohio Petroleum Corporation

Secretary-Treasurer - - - - - - J. Ed. Lytle
Union Producing Company

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

FLORIDA

SOUTHEASTERN GEOLOGICAL SOCIETY
Box 841
TALLAHASSEE, FLORIDA

President - - - - - - - - - - - I. J. Reed
The California Company

Vice-President - - - - - - - - Walter B. Jones
Geological Survey of Alabama

Secretary-Treasurer - - - - - - - H. A. Sellin
Magnolia Petroleum Company

Meetings will be announced. Visiting geologists and friends are welcome.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY
EVANSVILLE, INDIANA

President - - - - - - - - Charles W. Honess
Gulf Refining Company, Box 774

Vice-President - - - - - - J. Albert Brown
Sohio Petroleum Co.
Owensboro, Kentucky

Secretary-Treasurer - - - - - F. H. Latimer
Sun Oil Company
Evansville, Ind.

Meetings will be announced.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - - - R. R. Copeland, Jr.
The California Company, 1818 Canal Bldg.

Vice-President and Program Chairman - - - - - - - - - - - - Richard L. Denham
Humble Oil and Refining Company

Secretary-Treasurer - - - - - Philip R. Allin
Gulf Refining Company, Harvey, La.

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - - J. A. Moore
Union Sulphur Company

Vice-President - - - - - - - James M. Bugbee
Shell Oil Company, Inc.

Secretary - - - - - - - - - Lloyd D. Traupe
Ohio Oil Company

Treasurer - - - - - - - - - D. E. Newland
Magnolia Petroleum Company

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - - Rex P. Grant
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing
Vice-President - - - - - Richard H. Wolcott
Sohio Petroleum Company, Mt. Pleasant
Secretary-Treasurer - - - - Charles K. Clark
Pure Oil Company
402 2d Natl. Bank Bldg., Saginaw
Business Manager - - - Kenneth A. Gravelle
Gulf Refining Company, Box 811, Saginaw

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY

JACKSON, MISSISSIPPI

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Mellen & Monsour
Box 2571, W. Jackson Sta.
Vice-President - - - - - - - J. B. Wheeler
Stanolind Oil and Gas Company
Secretary-Treasurer - - - - - - H. L. Spyres
Skelly Oil Company

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY

ARDMORE, OKLAHOMA

President - - - - - - - - F. P. Schweers
The Texas Company, Box 539
Vice-President - - - - - Paul L. Bartram
Phillips Petroleum Company
Secretary-Treasurer - - - - - - Ben S. Curtis
Independent, Box 156

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA CITY GEOLOGICAL SOCIETY

OKLAHOMA CITY, OKLAHOMA

President - - - - - - - Gerald C. Maddox
Carter Oil Company
Vice-President - - - - - - Harold J. Kleen
Skelly Oil Company
Secretary-Treasurer - - - - Frederick H. Kate
Shell Oil Company, Inc.
965 First National Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon. Y.W.C.A.

SHAWNEE GEOLOGICAL SOCIETY

SHAWNEE, OKLAHOMA

President - - - - - - - - Delbert F. Smith
Oklahoma Seismograph Company
Vice-President - - - - - - Henry A. Campo
Atlantic Refining Company
Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY

TULSA, OKLAHOMA

President - - - - - - - - John G. Bartram
Box 591, Stanolind Oil and Gas Co.
1st Vice-President - - - - - Russell S. Tarr
Independent, Beacon Building
2nd Vice-President - - - - - John C. Maher
U. S. Geological Survey
Secretary-Treasurer - - - - - John R. Crain
Ashland Oil and Refining Company
Editor - - - - - - - - Robert F. Walters
Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY

CORPUS CHRISTI, TEXAS

President - - - - - - - - W. E. Greenman
The Texas Company, 902 Jones Building
Vice-President - - - - - - Dale L. Benson
Sinclair Prairie Oil Company, Box 480
Secretary-Treasurer - - - - - O. G. McClain
Consultant, 224 Nixon Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

DALLAS GEOLOGICAL SOCIETY

DALLAS, TEXAS

President - - - - - - - - John W. Clark
Magnolia Petroleum Company, Box 900
Vice-President - - - - - - Willis G. Meyer
DeGolyer and MacNaughton, Continental Building
Secretary-Treasurer - - - - John M. Clayton
Seaboard Oil Company, 1400 Continental Building
Executive Committee - - - - Fred H. Wilcox
Magnolia Petroleum Company

Meetings: Monthly luncheons by announcement. Special night meetings by announcement.

TEXAS

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

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Humble Oil and Refining Company
Vice-President - - - - - - - George N. Ely
Continental Oil Company
907 Peoples Bank Building
Secretary-Treasurer - - - - - B. F. Murphy
Amerala Petroleum Corporation
Box 2026

Luncheons: Each week, Monday noon, Blackstone Hotel.
Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

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Consultant, 1713 Esperson Building
Vice-President - - - - - - Charles H. Sample
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721 Bankers Mortgage Bldg.
Secretary - - - - - - - - A. F. Childers
Gulf Oil Corporation, Box 2100
Treasurer - - - - - - - - Wayne Z. Burkhead
Union Oil Company of California
1134 Commercial Bldg.

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO, TEXAS

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Peerless Oil and Gas Company
2023 Alamo National Building
Vice-President - - - - - - Marion J. Moore
Transwestern Oil Company, 1600 Milam Building
Secretary-Treasurer - - - - - Paul B. Hinyard
Shell Oil Company, Inc.
2000 Alamo National Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

FORT WORTH GEOLOGICAL SOCIETY
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Vice-President - - - - - - Edwin M. Rowser
The Texas Company, Box 1720
Secretary-Treasurer - - S. K. Van Steenbergh
Sinclair Prairie Oil Company
901 Fair Building

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - - Dolph S. Simic
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Vice-President - - - - - - Lynn L. Harden
Sinclair Prairie Oil Company
Secretary-Treasurer - - - - - D. T. Richards
George W. Graham

Meetings: Each week, Tuesday, 12:30 P.M., Texas Electric Auditorium; Each month, first Thursday evening. Special night meetings announced. All geologists always welcome.

WEST TEXAS GEOLOGICAL SOCIETY
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Vice-President - - - - - - W. J. Hilseweck
Gulf Oil Corporation, Box 1150
Secretary-Treasurer - - - - Charles A. Shaw
Forest Oil Corporation, Box 366

Meetings will be announced.

WEST VIRGINIA

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1901 Kanawha Valley Building
Vice-President - - - - - - W. B. Maxwell
United Fuel Gas Company, Box 1273
Secretary-Treasurer - - - - - R. L. Alkire
605 Union Building
Editor - - - - - - - - - J. D. Castner
Box 1433

Meetings Second Monday, each month, except June July, and August, at 6:30 P.M., Kanawha Hotel.

WYOMING

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P. O. Box 545

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Sinclair-Wyoming Oil Company
2nd Vice-President (Programs) - P. W. Reinhart
Shell Oil Company, Inc.
Secretary-Treasurer - - - David T. Hoenshell
General Petroleum Corporation

Informal luncheon meetings every Friday, 12 noon, Townsend Hotel. Visiting geologists welcome. Special Meetings by announcement.

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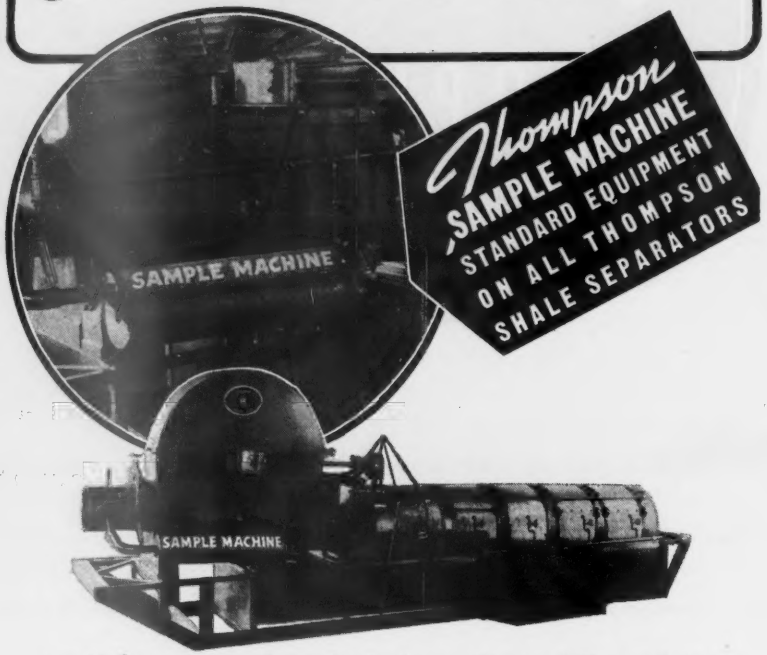

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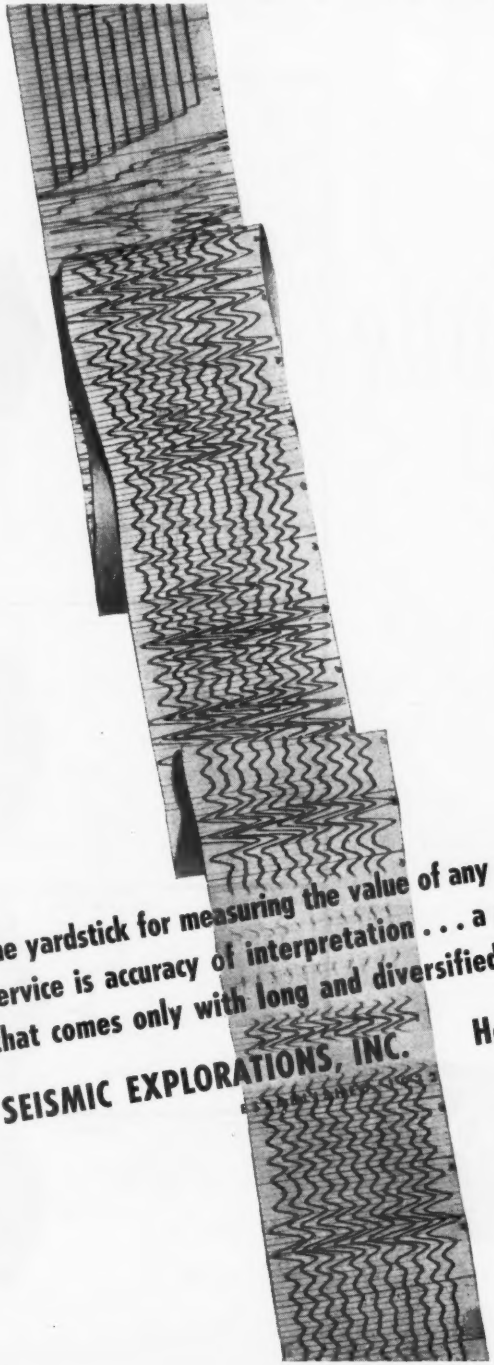

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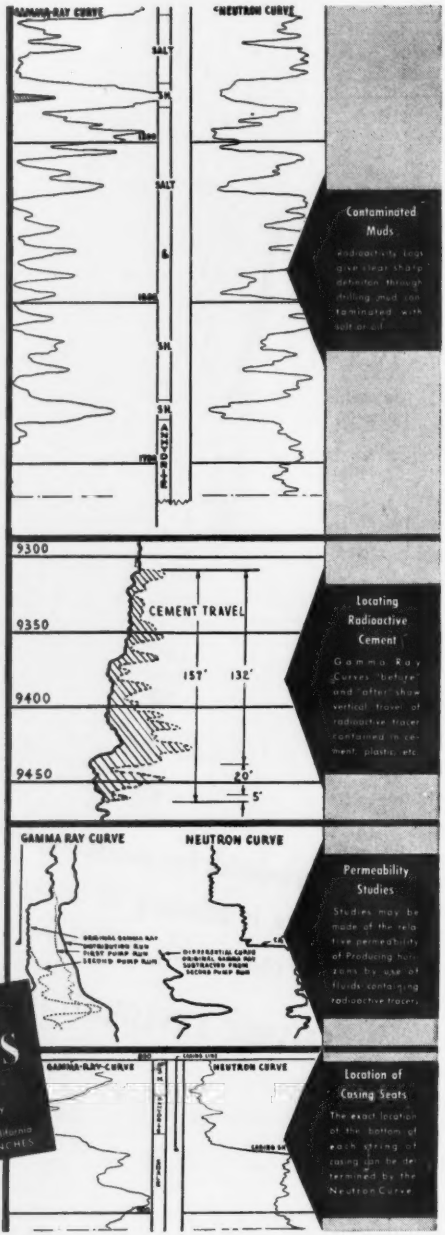

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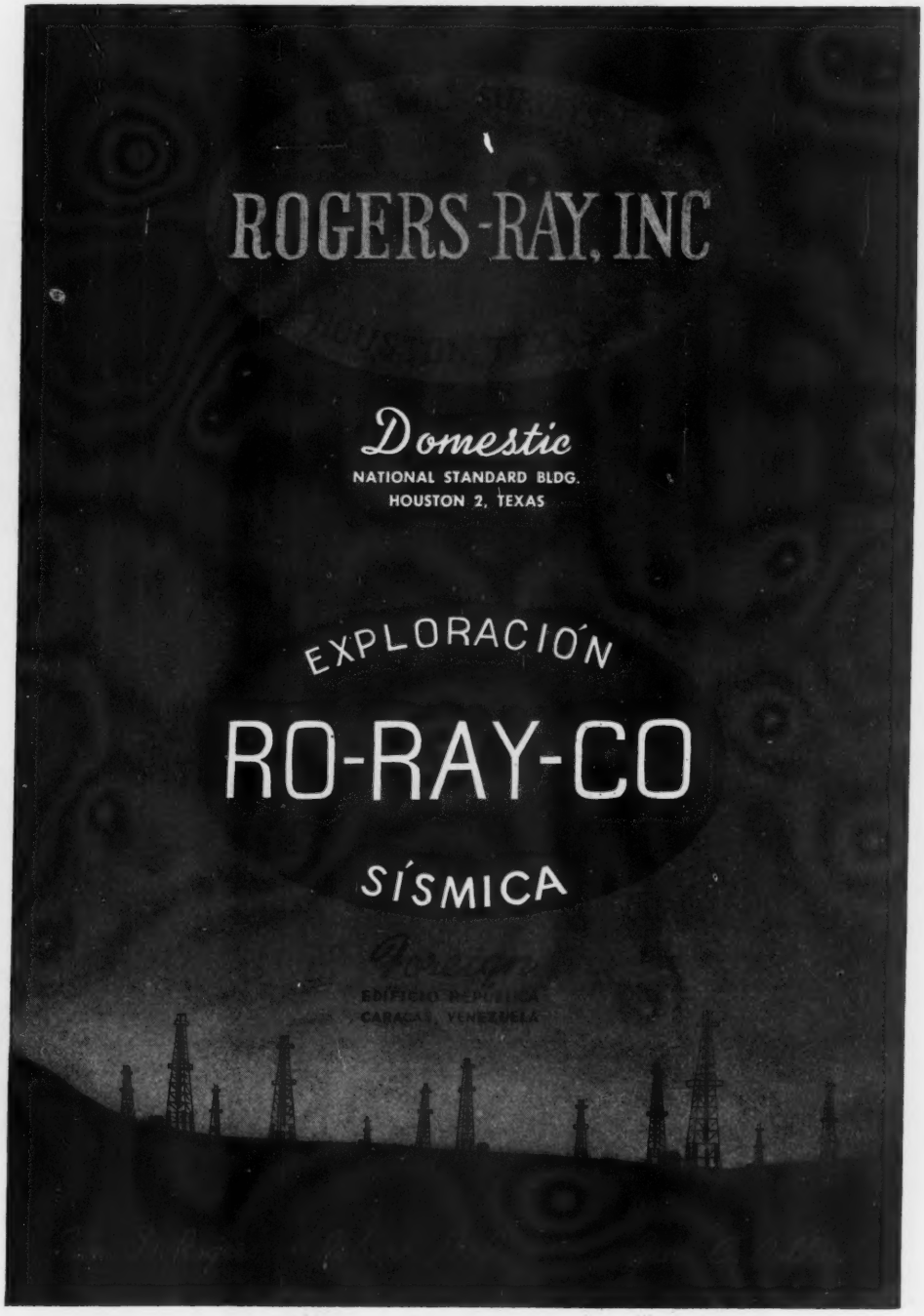
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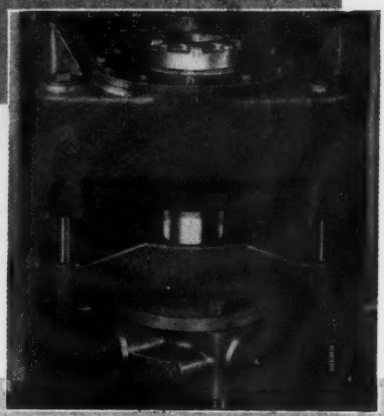

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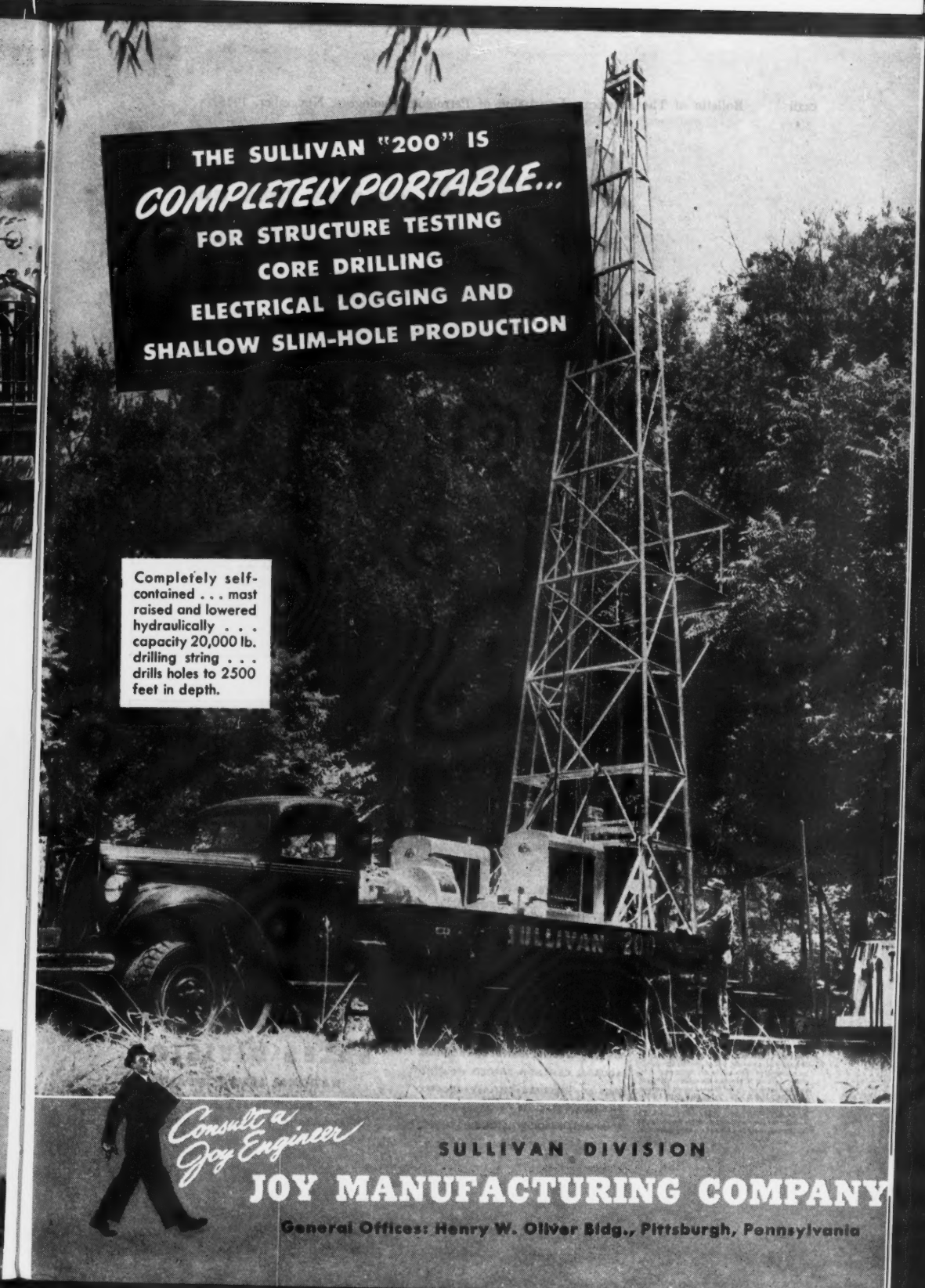
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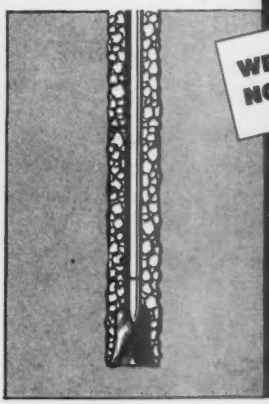

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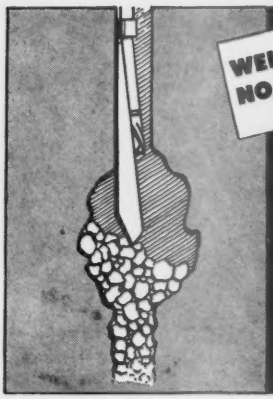

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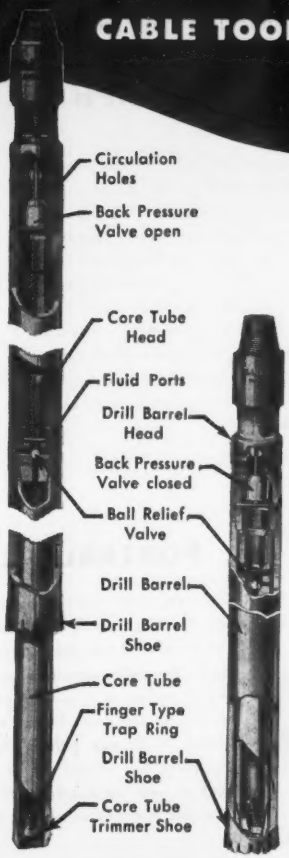

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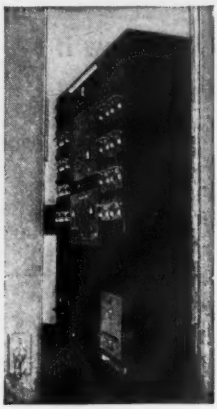

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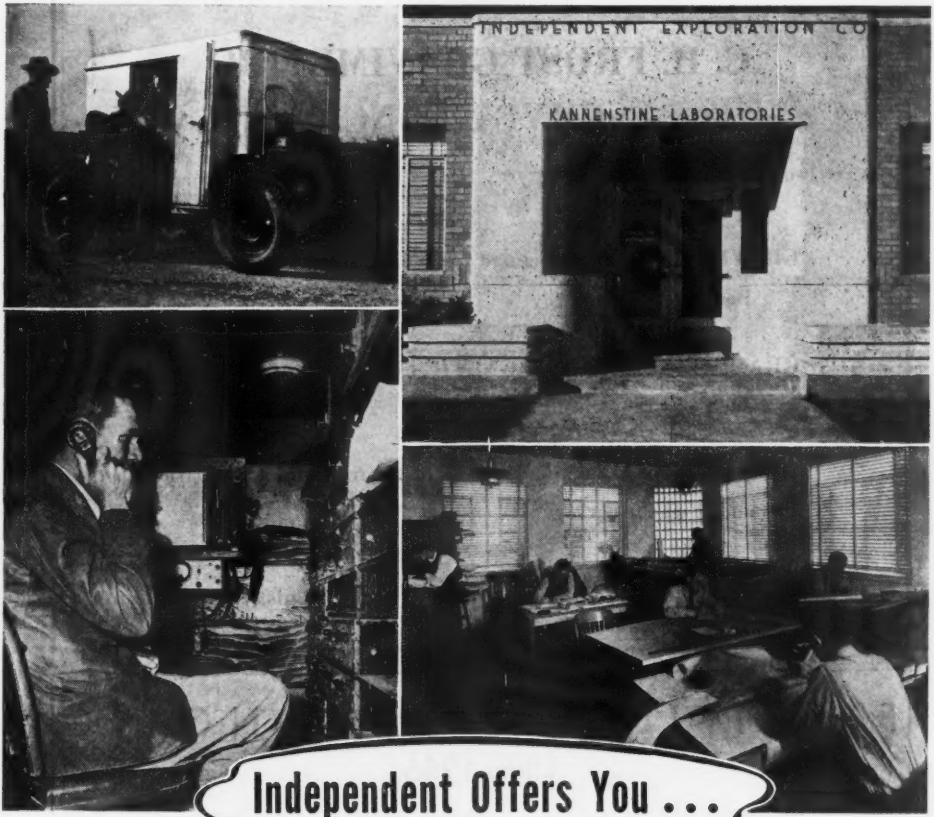

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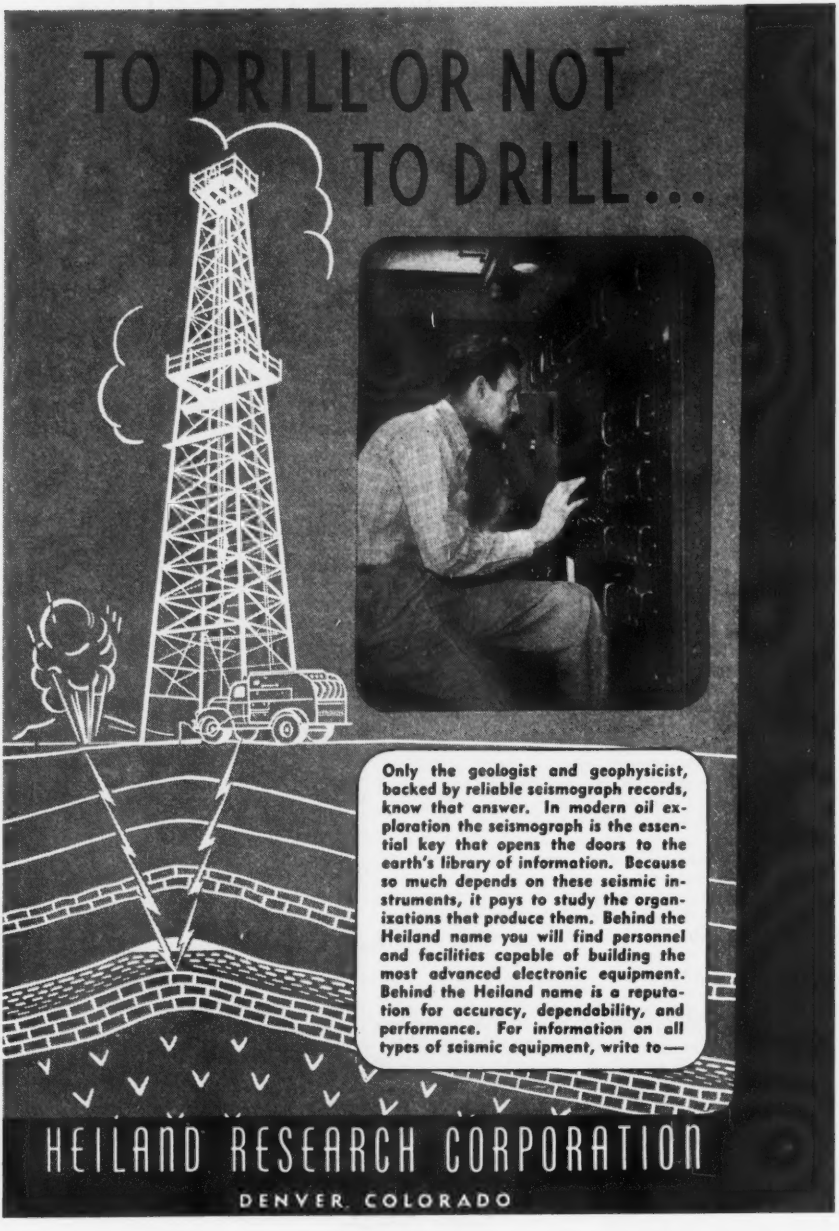
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by

F. M. VAN TUYL AND W. S. LEVINGS

With the cooperation of members of the staffs of the Departments of Geology, Geophysics, and Petroleum Engineering of the Colorado School of Mines

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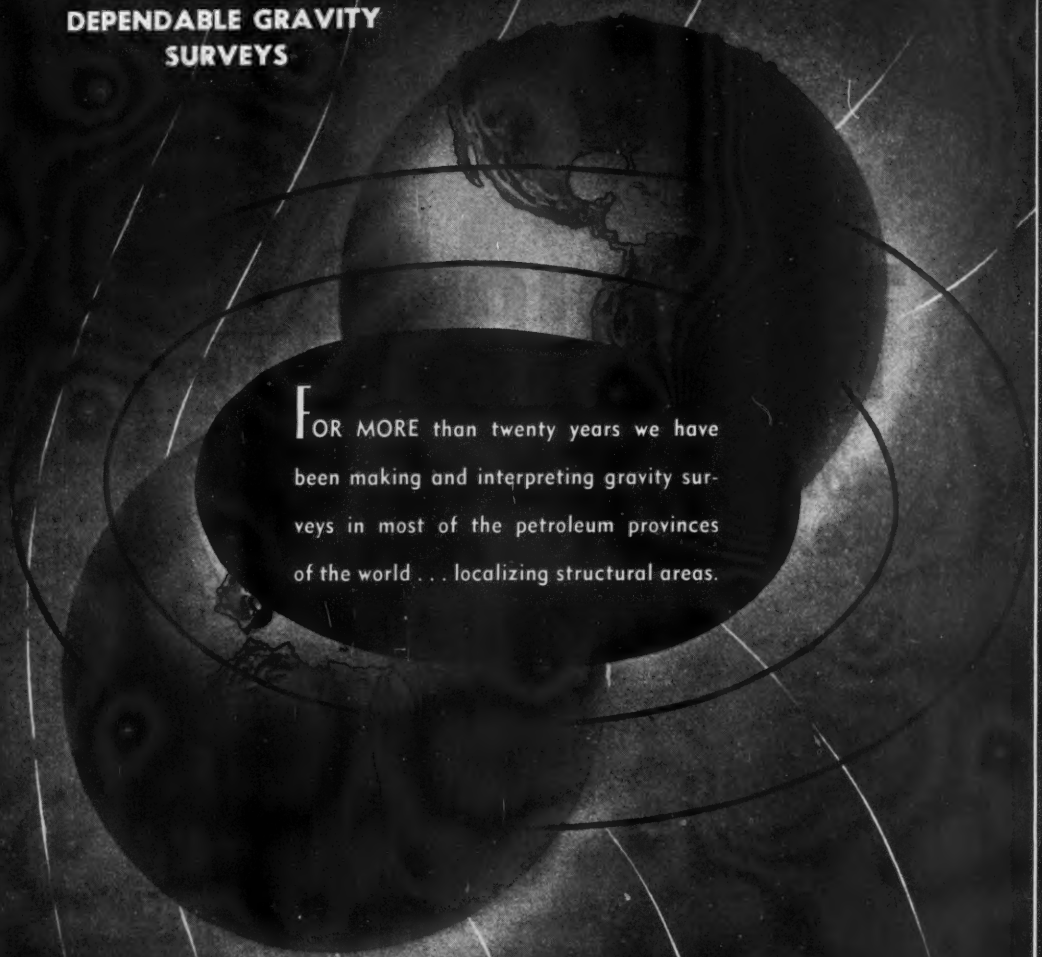

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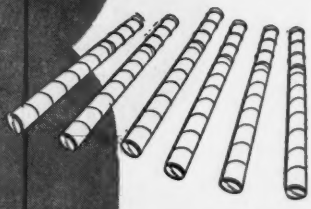

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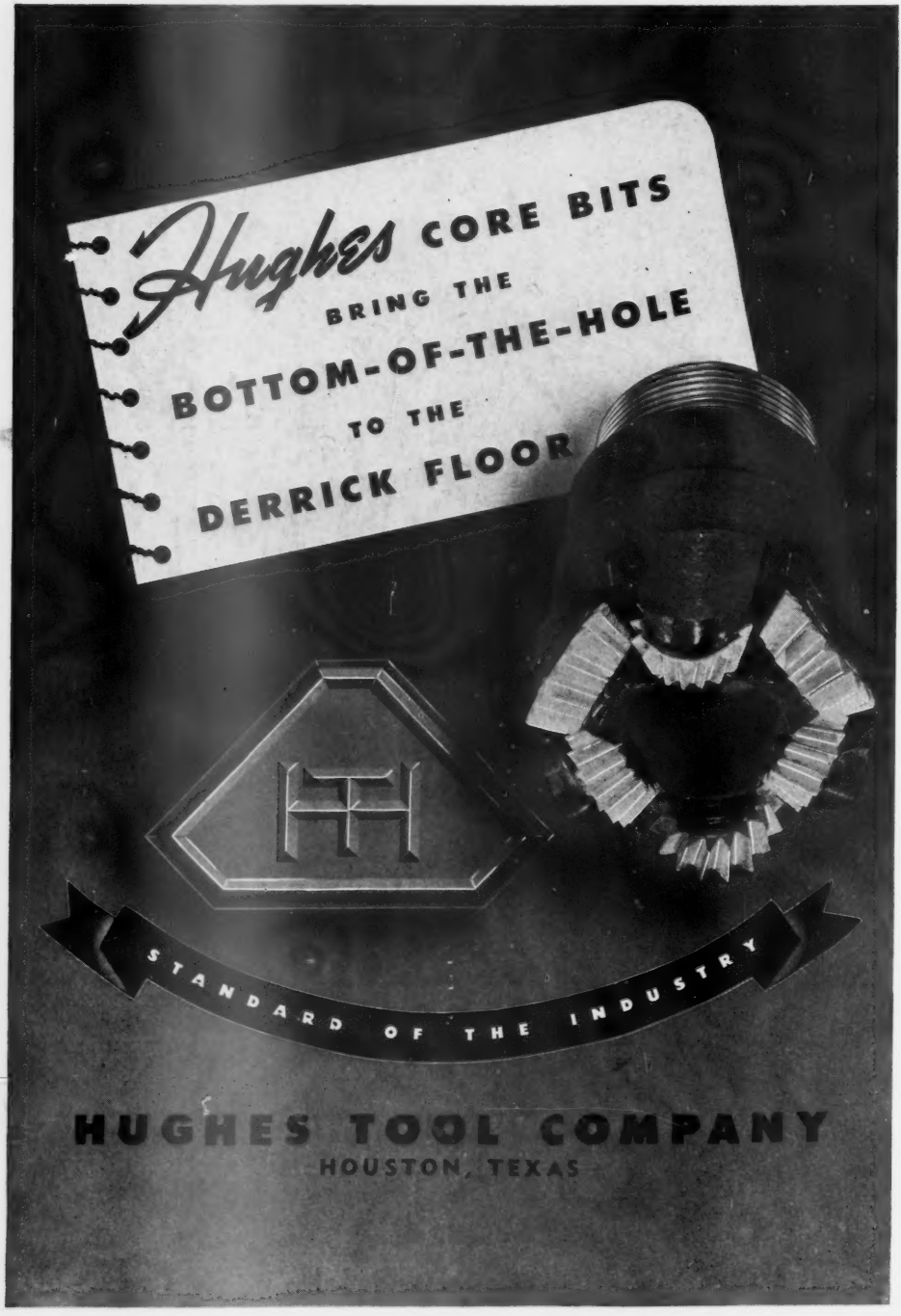
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